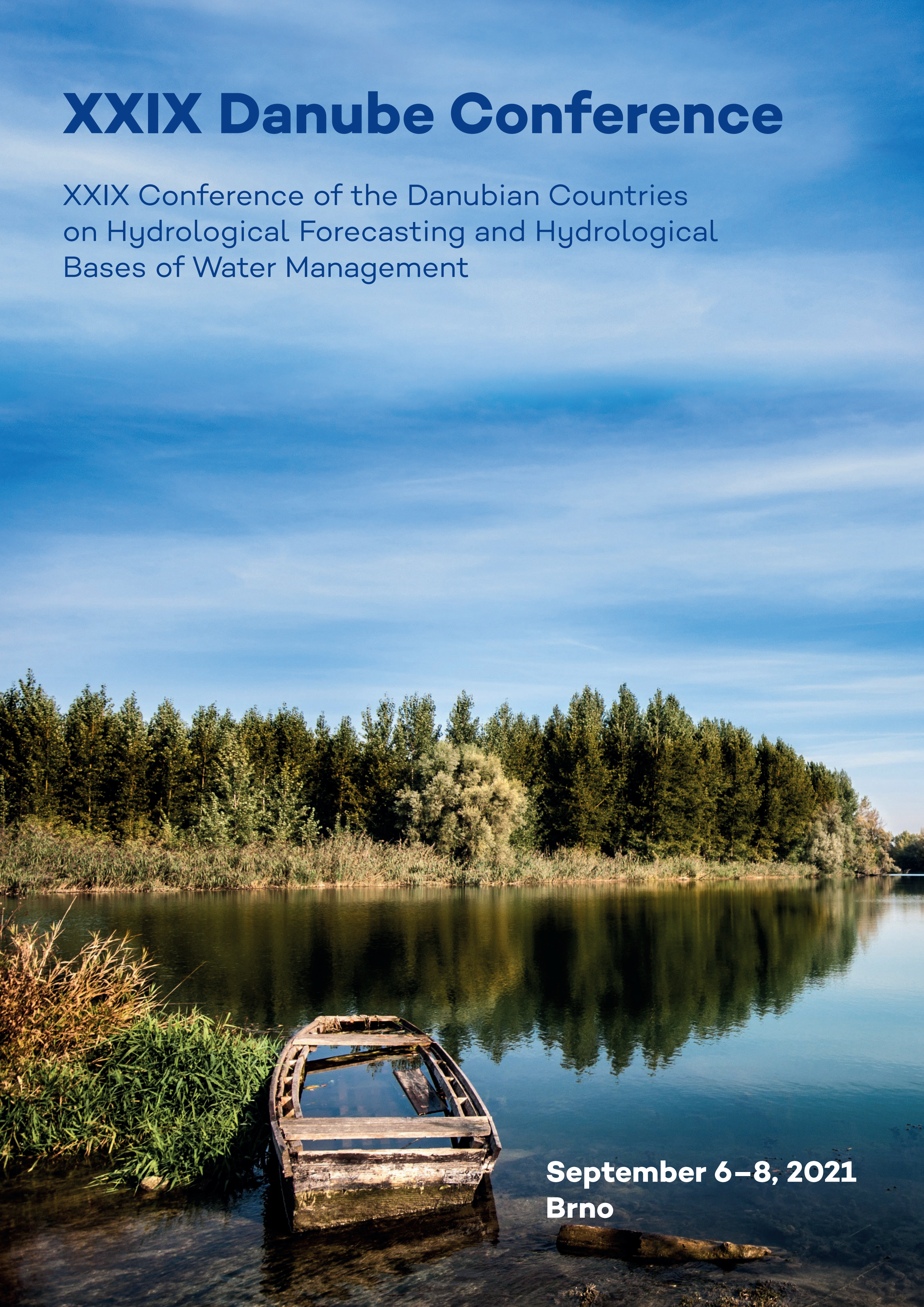
XXIX Danube Conference

XXIX Conference of the Danubian Countries on Hydrological Forecasting and Hydrological Bases of Water Management



September 6–8, 2021
Brno

Czech Hydrometeorological Institute
Czech National Committee for UNESCO
Intergovernmental Hydrological Programme Danube

XXIX Conference of the Danubian Countries

on Hydrological Forecasting and Hydrological Bases of Water Management

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Obsah

Introductory word

Conference of Danubian countries has become traditional platform for sharing outcomes of research and science among experts in the field of hydrology and water management in the most „shared“ basin of the World. Czech Republic agreed to host XXIX Conference after the last Conference in Kiev took place. But, as you all know, the World has changed since. Preparation of the XXIX Conference was not easy under the uncertainty of the pandemic development and at a certain time, a decision has been made to hold it virtually.

Virtual format is limiting due to lack of coffee break and evening discussions, which result in establishing of new professional connections and friendships. But, we feel that having a conference is important to preserve and stimulate existing connections in these difficult times.

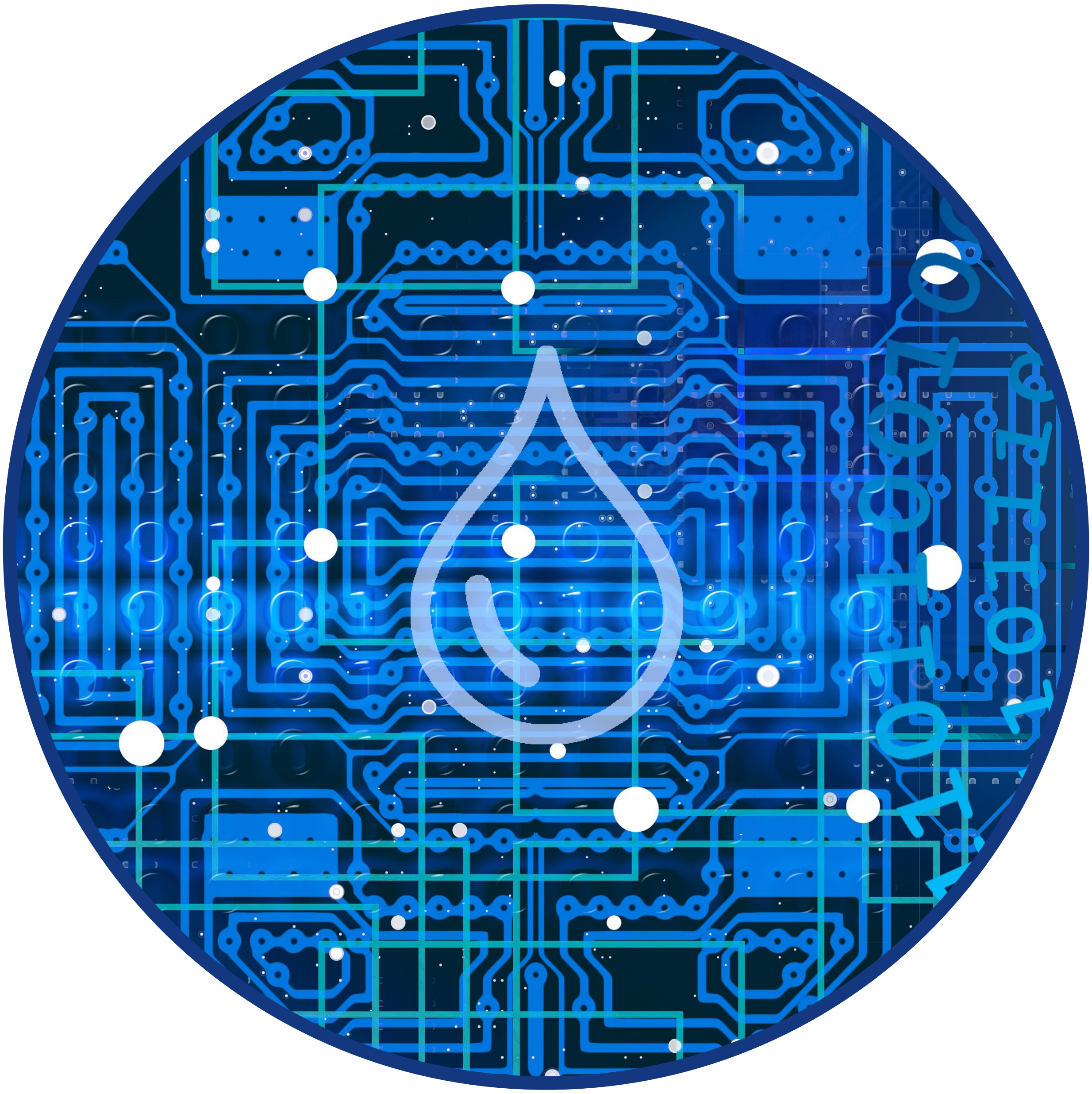
All the more so, we highly appreciated number of papers submitted that proved the interest of the community in scientific gathering and knowledge sharing. You can find collection of contributions in these Proceedings.

I urge you to read papers, and if interested in some, contact its authors, as you would during the nearest coffee break while in the in-person conference. Let’s try to stimulate dialog and cooperation despite the unpleasant current conditions. Keep in mind, that while there were periods of interrupted travelling among countries in Europe during last two years, the water of Danube and its tributaries never stopped running and connecting all countries that share its basin.

Jan Daňhelka

Topic 1

Data: traditional & emerging, measurement, management & analysis



Estimation of design discharges in terms of seasonality and length of time series

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Abstract

The paper deals with the effect of two factors on the accuracy of T-year discharge estimation resp. fluctuations in the estimation of these discharges. The AM method was used to analyze the effect of the time series length and seasonality (winter, summer) on the accuracy of T-year maximum discharges estimation. The series of daily discharges and peak discharges on the Topľa River at Hanušovce nad Topľou for the period of 1931–2015 were used as input data. The maximum annual discharges (AM) method was used with theoretical probability distributions Log-Pearson III, Gamma and Log-Normal.

Introduction

Floods occur in Europe very often and flood frequency analysis plays a major role in the design of hydraulic structures and flood control management. The flood frequency analysis deals with solution of the relationship between peak discharges of the flood waves and probability of their return period (*T*). Determining the specific values from a 100- to 1000-year flood for engineering practice is extremely complex.

All statistical methods which are used to estimate the floods with a very long return period are associated with great uncertainties. Such uncertainty is associated with several factors e.g. time series length, inclusion/non-inclusion of the historical floods into the time series, river regime or type of theoretical probability distribution. The estimation of the uncertainty at the design discharges was investigated for example by Coxon et al. (2015). The inclusion of historic pre-instrumental data to statistically analyzed data series was investigated in Elleder et al. (2013); Kjeldsen et al., (2014) or Pekárová (2019).

An important outcome of this study is how setting of time series at a gauging station can determine the magnitude of designed discharges.

Methodology

In our analysis we use one type of the theoretical probability distribution the Log-Pearson distribution type III (LP III). The advantage of this particular technique is that extrapolation can be made of the values for events with return periods well beyond the observed flood events. To estimate the distribution parameters, the method described in Bulletin17B was used (IACWD, 1982).

Subsequently, the LP III probability distribution was compared with other recommended probability distributions (Gamma and Log-normal) according to OTN ŽTP 3112-1: 03. To verify the accuracy of theoretical distributions, we used a non-parametric Kolmogorov-Smirnov goodness of fit test for the significance level $\alpha = 0.05$.

The Topľa is upland/lowland type of river in eastern Slovakia. The catchment drainage area is 1 506 km² with length of 129.8 km. The long-term mean daily discharge amounts at station Hanušovce nad Topľou was 8.1 m^3s^{-1} during period 1931–2015 and the maximum discharge during the analyzed period was 449 m^3s^{-1} (date: 06.04.1932).

Results

The effect of time series length on the T-year discharge estimation

For analyzing the effect of the length of the data series on the estimation of T-year discharges, the period of 1931–2015 was divided into two shorter periods: 1931–1973 and 1974–2015. We had chosen this approach because for the frequency analysis is recommended the length of the observation series 5T (FEH, 1999). Results are illustrated in Figure 1.

The effect of the seasonality on the T-year discharge estimation

For dividing the year into seasons, we proceeded from the analysis of the occurrence of floods and from the evaluation of the Topľa runoff regime during the year. The measured data were divided into two seasons:

- Summer season is from May to October, when peak discharges occur only from heavy rainfall.

• Winter season is from November to April, when peak discharges occur by combining heavy rainfall in the form of snow and rain as well as snow melting in the area.

The statistical data series were supplemented with maximum discharges in the given season, so that there are 85 measurements per season. Result are illustrated in Figure 1.

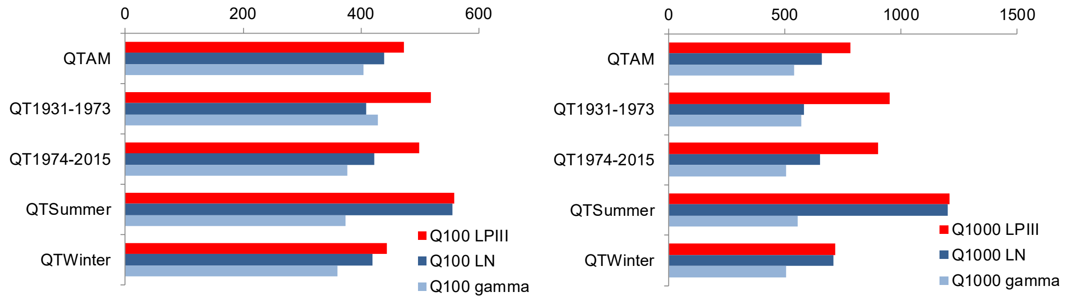

Fig. 1 Comparisons of the estimated maximum discharges with a return period of 100 and 1000 years according to the selected procedures

Conclusion

Results showed that not only the selection of the distribution function to estimate T-year discharges but also the processing of the statistical series affect the results of the estimation. The shorter periods showed higher estimations of the T-year discharges. The highest estimated values according the LPIII distribution was achieved for summer season. The lowest estimated value according the LPIII distribution was achieved for winter season. When interpreting the results, it should be borne in mind that the T-year maximum discharges are related to the length of the analyzed series and therefore estimated values with very high return periods are extrapolated and that each statistical method is burdened with some uncertainty that may be caused by alone method, but also the data, which may be burdened by a certain measurement error.

Acknowledgements

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References

Coxon, G., Freer J., Westerberg I. K., Wagener T., Woods R., and Smith P. J., 2015. A novel framework for discharge uncer-tainty quantification applied to 500 UK gauging stations, *Water Resour. Res.*, **51**, s. 5531–5546, doi:10.1002/2014WR016532.

Elleder, L., Herget, J., Roggenkamp, T., and Nießen, A. (2013): Historic floods in the city of Prague – a reconstruction of peak discharges for 1481–1825 based on documentary sources, *Hydrology Research*, **44** (2), s. 202–214.

FEH (1999): Flood estimation handbook. Wallingford (Institute of Hydrology), ISBN 0 948540 94 X.

IACWD (1982): Guidelines for determining flood flow frequency, Bulletin 17-B. Technical report, Interagency Committee on Water Data, Hydrology Subcommittee. 194 pp.

Kjeldsen, T. R., Macdonald, N., Lang, M., Mediero, et al. (2014): Documentary evidence of past floods in Europe and their utility in flood frequency estimation, *Journal of Hydrology*, **517**, s. 963–973. ISSN 0022-1694.

OTN ŽP 3112–1: 03 ME SR (2003): Quantities of surface and groundwater. Hydrological data of surface waters. Quantification of the flood regime. Part 1: Determination of T-year flow rates and T-year flow waves at larger flows Branch technical standard OTN ŽP 3112–1: 03, Ministry of Environment SR, Bratislava, 31 p. (in Slovak)

Pekárová, P., Miklánek, P. (eds.), 2019. Flood regime of rivers in the Danube River basin. Follow-up IX of Regional Cooperation of the Danube Countries in IHP UNESCO. IH SAS, Bratislava, 215 p. +527 p. app., DOI: 10.31577/2019.9788089139460.

Modelling snow water equivalent storage and snowmelt across Europe with a simple degree-day model

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Introduction

Recent studies identified snowmelt as a potential driver of the observed changes in the timing and the magnitude of floods in Central and Eastern Europe (Blöschl et al. 2017; 2019). They argue that warmer spring temperatures have led to earlier and decreased snowmelt, thus affecting floods. These findings are confirmed by the decreasing trend in spring snow cover extents across the northern hemisphere (Estilow et al., 2015).

In order to quantify the impact of snowmelt on the observed flood changes, a measure of the snow dynamics in time across Europe is needed. Satellite-based snow products are available for the most recent decades only, i.e., they are not suitable for being used for investigating the causes of flood changes in the past 50 years, and their use is restricted by the occurrence of clouds.

In this study, we model daily snow water equivalent storage and snowmelt across Europe with a simple degree-day model, using daily gridded precipitation and temperature data as inputs of the model. The accuracy of the daily maps of snow water equivalent storage is evaluated using MODIS snow cover images. The modelled daily maps are then used as covariates in a data-based attribution analysis of flood changes (Bertola et al., 2020).

Methodology

We model daily snow water equivalent storage and melt with a degree-day model, as a function of mean daily air temperature T_A and precipitation P:

$$M = \begin{cases} 0 & if\ T_A < T_m \\ \min\,(DDF \cdot (T_A - T_m); P_s) & if\ T_A \geq T_m \end{cases} \tag{1a}$$

$$P_s = \begin{cases} P & if\ T_A < T_S \\ P \cdot \frac{T_R - T_A}{T_R - T_S} & if\ T_S \leq T_A < T_R \\ 0 & if\ T_A > T_R \end{cases} \tag{1b}$$

Where M and P_s are the daily snowmelt depth and snow water equivalent storage, DDF is the degree day factor and T_m, T_s and T_R are the temperature thresholds that control the occurrence of melt, snow and rainfall, respectively. Here we assume $T_m = T_s = 0$°C, $T_R = 2.5$°C and $DDF = 2.5$ mm day^{-1} °C^{-1} (Parajka and Blöschl, 2008; He et al., 2014). As input data of the degree-day model, we use daily gridded E-OBS precipitation and temperature data for Europe (version 18.0e) with resolution 0.1 deg (Cornes et al., 2018). This gridded dataset covers the area 25N-71.5N x 25W-45E for the period 1950-2018. Daily maps of snow water equivalent storage and snow melt are obtained with resolution 0.1 deg.

The accuracy of the obtained snow water equivalent storage daily maps is quantitatively evaluated by using MODIS snow cover data over the period 2000-2010. The accuracy is quantified by an accuracy index, defined as follows:

$$Accuracy\ Index = \frac{A+D}{A+B+C+D} \cdot 100 \tag{2}$$

Where A, B, C, D are the cloud-free pixel-days (assumed threshold for clouds 40%) in the classification categories: snow in modal and MODIS (A); no-snow in model and snow in MODIS (B); snow in model and no-snow in MODIS (C); no-snow in model and MODIS (D).

Results

Snow water equivalent storage daily maps are obtained for Europe over the period 1960-2010. Figure 1a shows an example of a daily map for Austria. The spatial resolution is 0.1 deg, as in the daily gridded E-OBS precipitation and temperature data used as input of the model. The accuracy of the snow water equivalent daily maps is estimated and a sensitivity analysis of the effects of different modelled snow water equivalent (0, 1, 10 mm) and MODIS snow cover (10, 20, 40 %) thresholds on the index of overall accuracy are carried out. Figure 1b shows the results of the sensitivity analysis of the overall accuracy index for Austria.

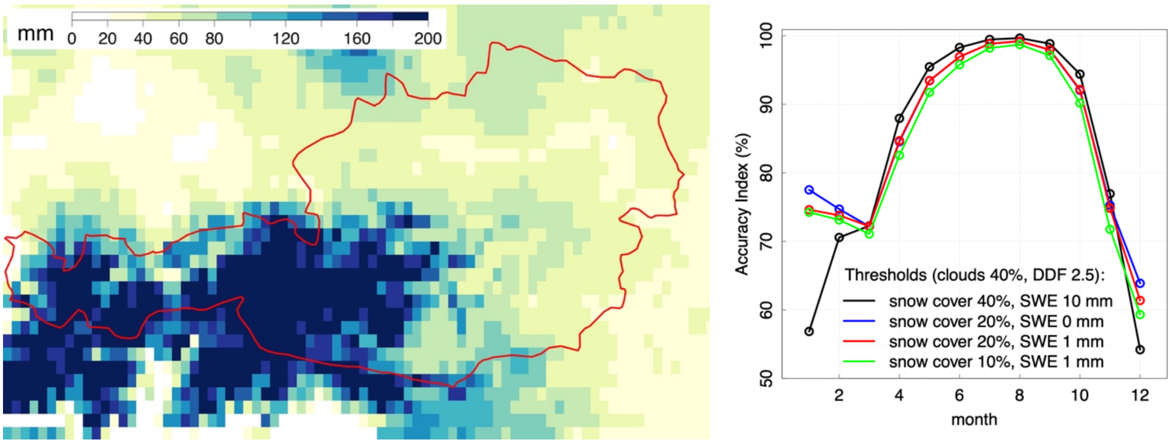

Fig. 1 Example of snow water equivalent storage daily map for Austria obtained for 2010-01-31 with resolution 0.1 deg (a) and accuracy of the modelled snow water equivalent for Austria evaluated with MODIS snow cover maps over the period 2000-09-01 to 2010-08-31 (b). Colours refer to different thresholds used to calculate the accuracy index.

Conclusion

We model snow water equivalent storage and snowmelt with a simple degree-day model across Europe. Daily maps are generated, and their overall accuracy is evaluated with MODIS snow cover data. Starting from the modelled daily maps, series of catchment-averaged snowmelt are extracted for several catchments in Europe and are used as potential drivers of flood changes to perform a data-based attribution analysis (Bertola et al., 2020).

Acknowledgements

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References

Bertola, M. et al. (2021) Do small and large floods have the same drivers of change? A regional attribution analysis in Europe, *Hydrology and Earth System Sciences*, **25** (3), s. 1347–1364.

Blöschl, G. et al. (2017) Changing climate shifts timing of European floods, *Science*, **357** (6351), 588–590.

Blöschl, G. et al. (2019) Changing climate both increases and decreases European river floods, *Nature*, **573** (7772), s. 108–111.

Cornes, R. C. et al. (2018) An Ensemble Version of the E-OBS Temperature and Precipitation Data Sets, *Journal of Geophysical Research: Atmospheres*, **123** (17), s. 9391–9409.

Estilow, T. W., Young, A. H. and Robinson, D. A. (2015) A long-term Northern Hemisphere snow cover extent data record for climate studies and monitoring, *Earth System Science Data*, **7** (1), s. 137–142.

He, Z. H. et al. (2014) Estimating degree-day factors from MODIS for snowmelt runoff modeling, *Hydrology and Earth System Sciences*, **18** (12), s. 4773–4789.

Parajka, J. and Blöschl, G. (2008) Spatio-temporal combination of MODIS images – Potential for snow cover mapping, *Water Resources Research*, **44** (3), s. 1–13.

Interactions of water chemistry in headwaters with wetlands: Comparative study for selected Czech mountains

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Introduction

Headwater streams are important both for the local aquatic ecosystem and for ecosystem goods and services. They are also very sensitive to any input of pollutants or climatic changes and can be thus assumed as an initial indicator to these variations. Currently, the rising temperatures and the increased risk of extreme rainfall-runoff events lead to changes in the biogeochemistry of surface waters. Especially the increased risk of elevated concentrations of organic matter, which could have a negative effect on human health because of the possible formation of disinfection by-products after water treatment. Study of the water quality changes related to different catchment's conditions is necessary to develop appropriate strategies for water quality preservation.

Methodology

The dependency of 15 physicochemical parameters and specific runoff in 6 catchments in Šumava Mts. headwaters and in 2 catchments in Krušné hory Mts. headwaters were analysed through correlation analysis with Spearman *r* coefficients (Spearman, 1904). Missing data were deleted pairwise. Principle component analysis (PCA) was performed in Excel using the XLSTAT Software (Addinsoft, 2018) for 16 physicochemical parameters, 8 catchment characteristics and discharge. For evaluating the changes of water chemistry during different rainfall-runoff events, simple C/Q hysteresis loops were examined for specific conductivity (SC) and pH.

Results

Regression between physicochemical parameters and discharge

Increased concentrations of organic matter and their higher release during greater discharges were observed in catchments with > 20 % of wetlands dominated by peat (Fig.1). Catchments with higher wetland cover were represented by higher TP, $N\text{-}NO_3^-$ and a significant decrease in pH during high streamflow rates. Higher mean concentrations of Fe were also detected, but discharge was not the main driver of higher release of Fe in catchments with > 20 % of wetlands. Concentration of Fe was correlated with COD_{Mn} concentration more than by pH or discharge. Iron and organic matter mobilization in catchments was influenced by wetland area, but the strongest correlation of Fe and COD_{Mn} was noticed in the catchment with a relatively small proportion of wetlands (8 %) and peatbogs (2.3 %), but with 70 % of damaged forest cover in the catchment.

An analysis of specific conductivity and pH during rainfall-runoff events

The analysis of SC and pH changes during rainfall-runoff events showed that the type of rainfall-runoff event affects the velocity of pH changes. The decrease of pH was much more rapid during consecutive summer rainfall-runoff events than during a snowmelt event and after a long dry period. The changes of SC were controlled not only by the type of rainfall-runoff event, but also by the hydrological preconditions of the catchment. Table 1 summarizes the types of C/Q hysteresis loops observed.

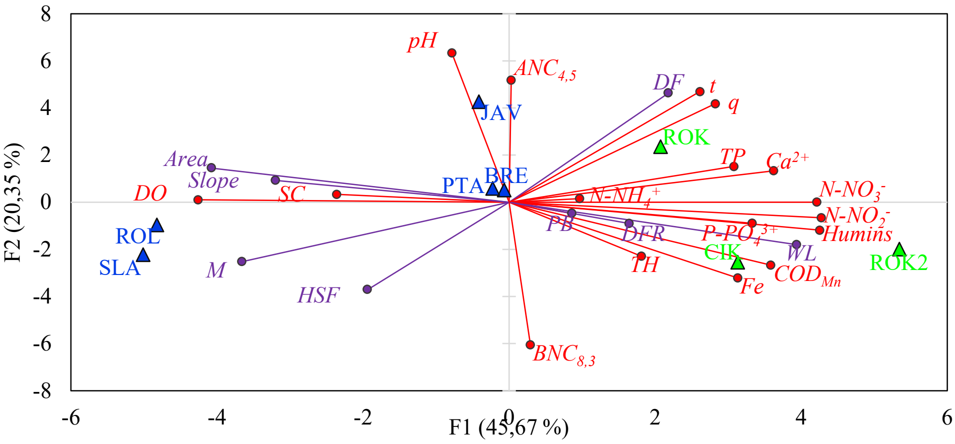

Fig. 1 Principal component analyses (PCA) of measured parameters, catchment characteristics and discharge in 8 catchments (2013–2019). Individual profiles: Filled blue triangles (< 20 % wetlands), filled green triangles (>20 % wetlands). SC = specific conductivity, t = water temperature, DO = dissolved O_2, TH = total hardness, TP = total phosphorus, Fe, COD_{Mn} = chemical oxygen demand, ANC4.5 = acid neutralization capacity, BNC8.5 = base neutralization capacity, HSF = healthy spruce forest, DF = damaged forest, DFR = decayed forest with partly regeneration, M = meadow, WL = wetlands, PB = peatbog, q = discharge.

Table 1 Classification of C/Q hysteresis loops at each sampling site during rainfall-runoff events, 2014–2016; SC = specific conductivity, Q = discharge. pink background = clockwise, blue background = counter-clockwise, green background = eight-shaped, yellow background = mixed loop class, NE = Not evaluated.

Profile	Consecutive summer rainfall-runoff events				After long-lasting dry periods		Spring snowmelt
	9th July 2014	12th July 2014	14th July 2014	22nd July 2014	8th October 2015	16th October 2015	18th April 2016
	SC/Q hysteresis loop						
PTAms	2	2	2	2	2	2	-NE-
CIKms	2	2	2	2	2	2	2
BREms	5	2	-NE-	5	5	5	3
ROKms	5	2	2	2	2	5	3
SLAms	1	1	3	1	6	6	1
	pH/Q hysteresis loop						
PTAms	1	1	1	1	3	1	-NE-
CIKms	1	1	1	1	1	1	1
BREms	1	4	-NE-	4	3	1	3
ROKms	1	1	1	1	1	1	1
SLAms	-NE-	-NE-	-NE-	-NE-	-NE-	-NE-	-NE-

Conclusion

Presence of peatlands and waterlogged spruce forests had decisive influence on the biogeochemistry (mainly for COD_{Mn}, humins, Fe, $P\text{-}PO_4^{3-}$ TP, and $N\text{-}NO_3^-$). High flow rates influence the release of greater amounts of organic matter (COD_{Mn}, humins), and $N\text{-}NO_3^-$ especially. Concentration of Fe was correlated with natural organic matter more than with pH or discharge. While changes in pH during rainfall-runoff events varied mainly in velocity, changes in SC also varied in different course in relation to catchment preconditions.

Acknowledgements

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References

Addinsoft (2018) XLStat reference manual. Paris: Addinsoft.

Spearman, C. (1904) The proof and measurement of association between two things. *American journal of psychology*, **15** (1), 72–101.

Qualitative analysis of surface waters of danube river (within borders of ukraine)

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Introduction

Today, the issue of surface water quality assessment is extremely relevant. Virtually all major rivers in Ukraine are integrated into a single hydrological system that operates both in our country and abroad.
Migration of pollutants with river waters from one state to another indicates its international character, the need to combine efforts of states to protect and restore transboundary rivers, in particular, harmonization of national and international law, international environmental cooperation. To improve transboundary monitoring of surface water quality, it is necessary to coordinate decisions in the field of water management with other countries that share transboundary watercourses, disseminate environmental and water management information, develop common criteria for assessing the ecological status of river basins, etc. (Gopchak et al., 2019; Snizhko, 2001; Yatsyk, 1997). Therefore, timely monitoring of the quality of surface waters of river basins is a necessary task to analyze and summarize information on the state of water bodies, forecast its changes and develop scientifically sound recommendations for appropriate decisions in the use, protection and conservation of water bodies and resources.
The aim of the study was to assess the quality of surface waters of the Danube River within its Ukrainian part.

Methodology

Ecological assessment of surface water quality of the Danube River was carried out using the system of classification of standards for assessment of surface water quality of Ukraine in accordance with the "Methodology of ecological assessment of surface water quality by relevant categories" (Methods…, 1998).
This technique is based on the values of three blocks of indicators: block of salt composition (I_1), block of tropho-saprobiological (ecological-sanitary) indicators (I_2), block of indicators for specific toxic substances (I_3). They reflect a wide range of hydrophysical, hydrochemical, hydrobiological and other indicators of aquatic ecosystems. Based on the values of block indices (I_1, I_2, I_3), and according to the standards of surface water quality, the integrated (environmental) index (I_E) was calculated, allowing for class and category of surface water quality to be determined.

Results

The Danube River is a transboundary river that flows through Europe. The total area of the Danube river basin is 817 thousand km^2 (8% of the total territory of Europe). The largest tributaries of the Danube, which originate in Ukraine – the rivers Tisza, Prut, Siret contributing about 15 km^3 of water per year. This is only 7.3% of the annual runoff of the Danube. On the territory of Ukraine only a small section of Danube (170 km) flows, from the city of Reni to its mouth (Polishchuk, Shega, 1998).
There are 17 countries within the Danube River Basin, and environmental pollution is a serious problem both for the Danube Basin as a whole, and for the section of the Danube River located in Ukraine. (World Wide Fund for Nature, 2002). The ecological condition of the river's surface waters is influenced by various factors. The main source of pollution of the Danube River within Ukraine is wastewater from enterprises, housing and communal services.
To assess the surface water quality of the Danube, four state monitoring points were selected, which allowed to characterize the hydroecological condition of the river within the territory of Ukraine from Reni (163 km from the mouth of the river) to Vilkove (20 km).
The worst data from hydroecological observations of water quality on the Danube River, conducted in 2019 by laboratories of the State Water Resources Agency of Ukraine, was used as initial data for calculations.
The results of ecological assessment of surface waters of the Danube River according to block indices (I_1, I_2, I_3) are given in Table 1.

Table 1 Ecological assessment of the surface water quality of the Danube River according to block indices (I_1, I_2, I_3)

#	Observation point (distance from the mouth of the river)	The values of the indices											
		I_1				I_2				I_3			
		value	category	sub category	class	value	category	sub category	class	value	category	sub category	class
1	r. Danube, Reni (163 km)	3,7	4	3-4	III	4.7	5	4-5	III	3.3	3	3(4)	II
2	r. Danube, Izmail (94 km)	3.7	4	3-4	III	4.8	5	5(4)	III	3.5	4	3-4	III
3	r. Danube, Izmail (48 km)	3.7	4	3-4	III	5.1	5	5	III	4.0	4	4	III
4	r. Danube, m. Vilkove (20 km)	4.3	4	4(5)	III	4.9	5	5(4)	III	3.3	3	3(4)	II

By analyzing the indicators of the content of pollutants in the waters of the Danube River, it was found that the largest exceedances of the normative values of the TLV were all related to COD. The cause of such pollution is the insufficient treatment of wastewaters by sewage treatment plants.
According to the final Integrated Ecological Index (I_E), the surface waters of the Danube in all observation points belong to class III of the water quality category 4 and are characterized as "satisfactory" in condition and "polluted" by their degree of purity (Table 2).

Table 2 Combined ecological assessment of surface water quality of the Danube River (I_E)

#	Observation point (distance from the mouth of the river)	I_E	Category	Subcategory	Class	Condition by class, category	Degree of purity by class, category	Condition by subcategory	Degree of purity by subcategory
1	r. Danube, Reni (163 km)	3.9	4	4(3)	III	satisfactory, fairly good	polluted, slightly polluted	satisfactory with a disposition towards the good	slightly polluted with a disposition towards pure
2	r. Danube, Izmail (94 km)	4.0	4	4	III	satisfactory, fairly good	polluted, slightly polluted	satisfactory	slightly polluted
3	r. Danube, Izmail (48 km)	4.3	4	4(5)	III	satisfactory, fairly good	polluted, slightly polluted	satisfactory with tendencies towards mediocre	slightly polluted with tendencies towards moderately polluted
4	r. Danube, m. Vilkove (20 km)	4.2	4	4	III	satisfactory, fairly good	polluted, slightly polluted	satisfactory	slightly polluted

Conclusion

Thus, results of 2019 observations indicate satisfactory quality of surface waters of the Danube River within Ukraine. The quality of water according to the Integrated Ecological Index (I_E) corresponds to the third class, which indicate the need for targeted efforts, in order to improve the ecological situation and protect the ecosystem of the Danube River.
Determining the quality of water in the Danube River is important for assessing current and future ecological conditions in its basin, in order to further understand key areas of water protection activities, and to improve ecological conditions of the river, by establishing environmental standards for water quality. All this outlines the prospects for further research.

References

Gopchak I, Basiuk T, Bialyk I, Pinchuk O, Gerasimov I (2019) Dynamics of changes in surface water quality indicators of the Western Bug River basin within Ukraine using GIS technologies. *Journal of Water and Land Development.* No. **42** (VII–IX), 67–75. DOI: 10.2478/jwld-2019-0046.

Methods of ecological assessment of surface water quality by relevant categories. (1998). 28 pp.

Polishchuk VV, Shega VV (1998) Historical biography of the Danube or urgent problems of the present in the light of features of the big European river. Kyiv, 680 pp.

Snizhko SI (2001) Assessment and forecasting of natural water quality: a textbook, 264 pp.

World Wide Fund for Nature, 2002. A vision for the Danube Delta, Vienna / Odessa.

Yatsyk AV (1997) Ecological foundations of rational water use. Kiev, 640 pp.

Influence of 30-year reference periods on characteristic periodic discharges

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Introduction

River discharges are constantly changing over time. The temporal variability of river flows in Slovenia is high. Climate is the main factor affecting the flow regime. River flows mainly depend on the height of precipitation, its temporal and spatial distribution, air temperature and the height and duration of the snow cover. The inter-annual variability of flows is also high. The data of national hydrological monitoring show a decreasing trend of river discharges in Slovenia (Kobold et al., 2012).

For comparison between different data sets reference periods are used to allow comparison among different data on a consistent basis. Period averages of climatological and hydrological data serve as a measure against which recent or current observations can be compared. It is common practice to compare current data with averages from a long-term comparison period. The World Meteorological Organization (WMO) recommends to use 30-year periods of reference. The 30-year reference period was set as the standard mainly because only 30 years of data were available when the recommendation was first published (WMO, 2011). The current reference period is 1981–2010 (WMO, 2017).

The Decree on criteria for determination and on the mode of monitoring and reporting of ecologically acceptable flow (Official Gazette of the Republic of Slovenia, No. 97/09) recommends the data from the last 30 years for the calculation of mean and mean low periodic discharges.

Methodology

Using different 30-year periods, an analysis of 30-year characteristic average discharges was performed. The historical practice of climate averages, described in the manuals and technical regulations of the World Meteorological Organization (WMO, 2011; WMO, 2019), dates back to the first half of the 20th century. The general recommendation is to use 30-year reference periods. At the 17th World Meteorological Congress in 2015, the definition of the standard climatological average changed and now refers to the last 30-year period ending with 0 at the end of the year (currently this period is 1981–2010) instead of 30-year periods, which do not overlap (1901–1930, 1931–1960, 1961–1990, and in the future 1991–2020) as it was before (WMO, 2017). However, a period of 30 years is not enough to calculate extreme statistics and return periods. In these cases, the entire available data period is usually taken.

In the analysis of trends and periodic averages, the results are strongly influenced by the period considered and the length of the time series. For the four water gauging stations on the Slovenian rivers in the Danube River Basin with the longest data sets, the common period of data since 1926 was taken. Period averages of the most commonly used characteristic discharges in hydrology (mean annual discharge, the lowest annual discharge and the highest annual discharge) were calculated for different 30-year periods according to WMO recommendations (WMO, 2017) and internal state regulation (Official Gazette of the Republic of Slovenia, 2009).

Results

For the gauging stations Litija on the Sava River, Metlika on the Kolpa River, Moste on the Ljubljanica River and Nazarje on the Savinja River, the results of average discharges for the 30-year periods 1931–1960, 1961–1990, 1981–2010 and 1989–2018 are shown in Fig. 1. With the exception of the Ljubljanica, the highest values of average periodic discharges were reached for the period 1931–1960. For all stations, the trend of discharges is negative. The lowest values are for the period 1981–2010. In the last 30-year period (1989–2018), a slightly positive trend has already been detected compared to 1981–2010. Similar results were obtained for the average low flows in the period, while the trends of average high periodic peaks are positive (Kobold, 2020).

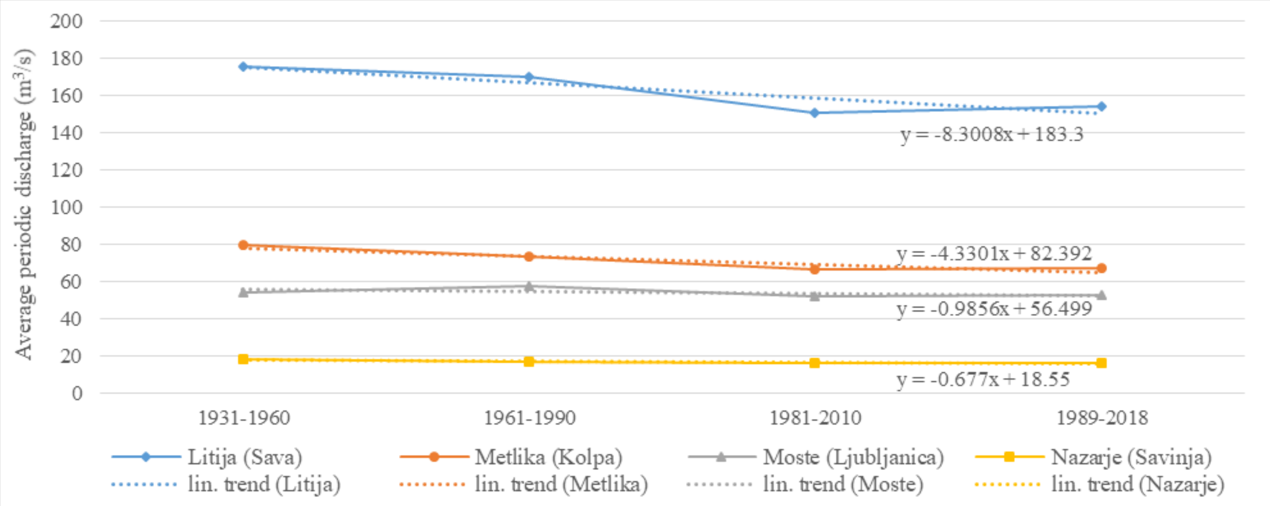

Fig. 1 Average periodic discharges for the four 30-year periods and trend for the gauging stations with the longest data sets in Slovenia.

Conclusions

The choice of the long-term reference period influences the values of the characteristic discharges, so it is necessary to indicate the reference period when publishing the results of analyses. The average discharges for different 30-year periods can vary greatly. Ecologically acceptable flow in Slovenia is determined from the value of average low flow for the last 30 years. Depending on the 30-year period used to estimate the average low discharge, different estimates can be obtained for the same watercourse or even the same location, and consequently the values of the ecologically acceptable flow when water rights are granted.

References

Kobold M (2020) Vpliv izbire primerjalnega obdobja na vrednosti obdobnih značilnih pretokov pri daljših časovnih nizih podatkov, Zbornik 31. Mišičev vodarski dan, Maribor, *Vodnogospodarski biro*, 105–108.

Kobold M, Dolinar M, Frantar P (2012) Sprememba vodnega režima zaradi podnebnih sprememb in drugih antropogenih vplivov, Zbornik prispevkov, I. kongres o vodah Slovenije 2012, Ljubljana, Slovenija, Fakulteta za gradbeništvo in geodezijo,
7–22.

Official Gazette of the Republic of Slovenia (No. 97/09) The Decree on criteria for determination and on the mode of monitoring and reporting of ecologically acceptable flow.

WMO (2011) Guide to Climatological Practices, WMO-No. 100, Geneva.

WMO (2017) WMO Guidelines on the Calculation of Climate Normals, WMO-No. 1203, Geneva.

WMO (2019) Technical Regulations, WMO-No. 49, Geneva.

Peak maximums on the rivers of the Prut and Siret basins (within Ukraine)

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Introduction

The maximum river runoff is one of the important extreme regime characteristics of river water runoff. It causes various manifestations of catastrophic situations (flooding of territories, settlements, destruction of bridges, buildings, hydraulic structures, etc.). The maximums on the rivers are characterized by the daily mean maximum discharge of water runoff (defined as an average over the periods daily measurement) or peak discharge of water runoff (the absolute maximum of the day). On small rivers, there could be significant differences in values between these maximum, but the larger the river, the smaller these differences. Especially, such differences can be traced in mountainous regions, where, flowing from mountains with large slopes, rivers pass into the foothills and then go to the plain or lowland (Lukianets et al., 2019b; Lukianets et al., 2019).
The main purpose of the study is to identify how the daily mean maximum and peak maximum of water runoff of the day on the rivers in the Prut and Siret basins are related. This is an influential issue in assessing and forecasting the hazard of the hydrological situation on rivers.
Prut and Siret are the rivers in southeastern Europe. They belong to the Danube river basin (Black Sea basin) and they are its left tributaries. Only the upper reaches of the Prut and Siret rivers are located within Ukraine. They originate in the Carpathian Mountains. The total catchment area of these rivers in Ukraine is 11300 km^2 (Lukianets et al., 2019a). The heights of the terrain in these basins are distributed as follows: 55% of the study area is within the heights of 200–400 m a.s.l, 16% – 400–800 m a.s.l and 29% – above 800 m a.s.l. Average annual precipitation in the Prut and Siret basins generally increases with the height of the area from 630–660 mm to 1400–1420 mm (Balabukh et al., 2011). In the water regime, spring floods are observed, but rain floods prevail in the warm season. They are those who acquire the nature of dangerous phenomena with destructive consequences and provide high maximums per year. The intensity of the development of rain floods in the basins of the Prut and Siret rivers can be represented by the following data. In the section of the gauging station on mountain rivers, the time interval between the onset of the precipitation core and the flood maximum from a drainage area of 1000–1200 km^2 is 6–10 hours (Grebin et al., 2012). Snow – rain floods of the cold period occur on the studied rivers, but they are not typical. The values of the maximum water discharge in 12–16 times exceed the values of the average annual water discharge on the rivers in the Prut and Siret basins (Obodovskyi et al., 2020). The mountainous part of the basins belongs to the main flow formation zone.

Methodology

To accomplish the tasks set, statistical methods for processing hydrometeorological information were used (determining the numerical characteristics of random variables, testing statistical hypotheses for the homogeneity of data series, statistical analysis of dependencies between variables, etc.). A database has been created for a long-term period – the daily mean maximum water discharge and the peak maximum water discharge corresponding them on the rivers of the Prut and Siret river basins. There are 12 gauging stations in the study area, which monitor the flow of water in rivers. Eleven of them are located in the Prut basin and 1 gauging station is in the Siret basin. At 83% of hydrological stations on the rivers of the Prut and Siret basins have an observation periods for water runoff of 54 ÷ 72 years, only 2 stations have an observation period less than 40 years.

Results

The overwhelming majority of the variation coefficients of the maximum water runoff on the rivers of the Prut and Siret river basins vary in the range of 0.8–1.0; the asymmetry coefficients have positive values and, in general, are in the range of 1.8–2.5. The observation series for the maximum water flow in the studied rivers are representative. The relative values of the root mean square errors do not exceed 15–20%.
A quantitative assessment of the homogeneity of the maximum annual water discharges at a 5% significance level on the rivers of the Prut and Siret basins was carried out according to the standard parametric criteria of Student and Fisher. One of the most stringent, the Wilcoxon test, was used from nonparametric criteria. Checking the

equality of mean values by Student's test (statistics t) and equality of variance by Fisher's test (statistics F) showed that the hypothesis of homogeneity of samples of the maximum annual water runoff for all rivers of the Prut and Siret basins is accepted. The result is the same for Wilcoxon's test (statistics of the number of inversions U).
To enable a spatial comparison of the maximum values on the rivers of the Prut and Siret basins, was used such characteristic as the specific discharge of water runoff. This indicator shows the amount of water (dm^3 or liter) flowing down in one second (1 s) from a unit area (1 km^2) of the river basin.
To clarify the differences in the values of the specific discharge of water runoff (daily mean maximum vie with the corresponding peak maximum) on the rivers of the Prut and Siret basins, we constructed dependences between the indicated characteristics. They turned out to be quite significant. The approximation coefficients R^2 vary from 0.59 to 0.97, which corresponds to the correlation coefficients r – from 0.77 to 0.98. But the ratios themselves between the daily mean maximums and the corresponding peak maximums on the rivers of the Prut and Siret basins are different. To identify patterns in these differences we constructed graphs of relations between the maximums with the average heights of the catchments and their areas.

Conclusion

The physical and geographical conditions of the Prut and Siret river basins (first of all, climatic and orographic) contribute to the formation of significant maxima on the rivers of the study area. In spatial terms, the study area has elements of mountain and foothill orography, therefore, the rivers have different conditions for the formation of maxima. It was revealed that the greatest ratio between the peak maximum and daily mean maximum is observed in mountain watersheds with average heights of 1 000–1 200 m. a.s.l. where, the peak maximums typically exceed in 1.8–2.0 times the daily ones. From catchments with average heights of 400 m a.s.l. such ratios decrease to 1.1–1.3. The largest specific discharges of water runoff are observed in small mountain catchment areas, where the peak maximum of specific discharge of water runoff reaches 3 000–3 500 $dm^3 \cdot s^{-1} \cdot km^{-2}$.

References

Balabukh Vira, Lukianets Olga (2011) Regional features of change of atmospheric processes in the river basins of overhead Prut-Siret and their influence on water regime of the rivers, XXVth Conference of the Danube Countries on Hydrological Forecasting and Hydrological Bases of Water Management, 98

Grebin VV, Lukianets OI, Tkachuk II (2012) An estimation of possibility of operative forecasting of rain floods is on the rivers of basins of Prut and Siret, *Ukrainian Hydrometeorological Journal*,Vol. **10**, s.164–175

Lukianets O, Moskalenko S (2019a) Generalization and multi-annual variability of the maximum annual runoff river water in accordance with the hydrographic zoning of Ukraine, *Hidrolohiia, hidrokhimiia i hidroekolohiia,* **2** (53), 6–20

Lukianets O, Moskalenko S (2019b) Correlation between daily mean maximums and peak maximums on the rivers of the Tisza basin within Ukraine, *Hidrolohiia, hidrokhimiia i hidroekolohiia*, **3** (54), 57–58

Lukianets O, Malytska L, Moskalenko S (2019) Maximum rivers runoff in the basin of Tysa and Prut within Ukraine, XXVIII Conference of the Danubian countries on hydrological forecasting and hydrological bases of water managemen, BOOK OF ABSTRACT, 47

Oleksandr Obodovskyi, Olga Lukianets, Oksana Konovalenko, Valeriy Mykhaylenko (2020) Mapping the Mean Annual River Runoff in the Ukrainian Carpathian Region, *Journal of Environmental Research Engineering and Management*, **76** (2), 22–33

Long-term discharge prognosis of rivers in the Danube River Basin

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Abstract

In this study, the changes in statistical characteristics of the selected rivers in the Danube basin were identified using analysis of the monthly and annual time series. In the second part, the relationship between runoff and North Atlantic Oscillation phenomena (NAO) will be discussed. The third part of this study is devoted to the long-term prediction of the monthly discharge by applying stochastic methods.

Introduction

The economic prosperity of each country is closely linked to the availability of sufficient water resources. Economic development and rising living standards generally lead to higher water consumption requirements. As water resources are limited, social and economic growth will be severely limited in many regions of the world in the future.

Amount of water in rivers (the largest utilizable water resources) fluctuates to great extent. In our latitudes, the considerable seasonal variability of runoff during the year causes serious problems during the period of the runoff surplus, as well as in water supply during the dry periods.

With the increasing period of observation of river flows, it is increasingly confirmed that the use of water resources is not limited only by their annual development, but also by multi-year variability. The correct identification (or possible clarification of the existence) of such long-term cycles in a particular region presents an opportunity to predict the runoff development in that region for 20–30 years in advance. For correct decisions in water resources management in each country, such estimates and predictions would have an immense economic importance (construction of water storage reservoirs, energy production in hydroelectric plants, need of the water for irrigation, etc.).

Methodology

It is generally expected that an increase in temperature will increase evapotranspiration in summer and reduce runoff. There are two main approaches to runoff forecasting in the coming decades:

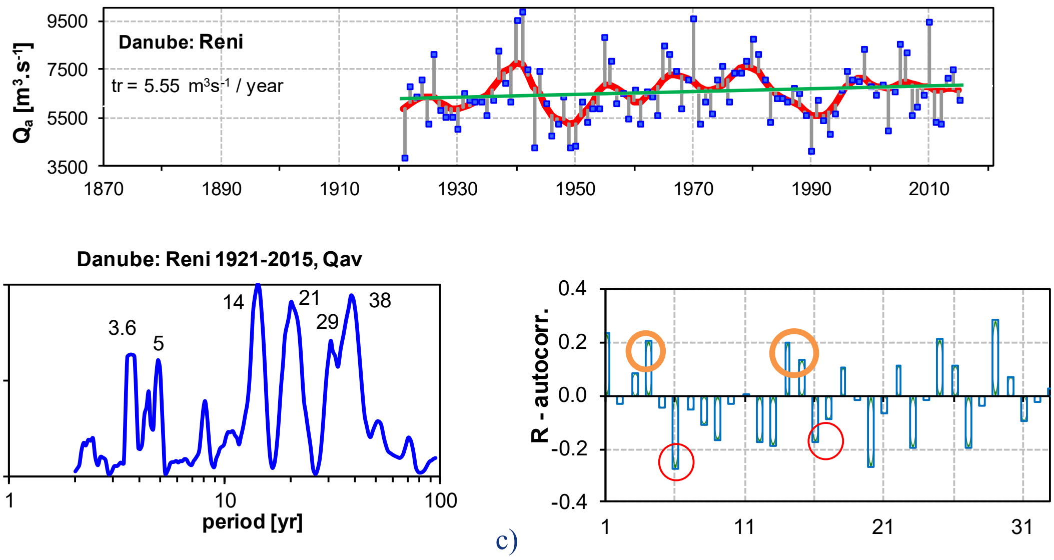
- Statistical analysis of long-term discharge series followed by prognosis using stochastic auto-regressive models;
- Application of hydrological rainfall-runoff models based on precipitation-temperature-stream runoff relations. The precipitation and temperature data are modified according to selected climate scenarios for future time horizons (most frequently 2050, 2075, or 2100).

In this study, the first method was used and changes in the statistical characteristics of flows were identified using a detailed statistical analysis of monthly and annual time series in selected rivers of the Danube basin. To analyze the long-term runoff variability, the daily discharge series from four water gauge stations: Danube: Bratislava gauge with 131,338 km^2 (Slovakia – SK); Tisza: Senta with 141,715 km^2 (Serbia – SR); Sava: Sremska Mitrovica with 87,966 km^2 (Serbia – SR); and Danube: Reni with 805,700 km^2 (Ukraine – UA) were used. The Tisza basin is one of the driest sub-basins in the Danube basin according to the specific yield. The daily discharge series of the Danube River were obtained from the database of the UNESCO project No.9 “Flood Regime of Rivers in the Danube River basin”.

Results

Multi-annual runoff variability identification

More than 60 years ago, by the studies of long-term storage requirements on the Nile River, Hurst (1951) discovered a special behavior of the hydrological and other geophysical time series, which has become known as the "Hurst phenomenon". This behavior is essentially the tendency of the wet years to cluster into wet periods, or of the dry years to cluster into periods of drought (Pekárová, 2009). In the first part of the study, we focused on dry and wet multi-annual cycles identification in the annual discharge time series (Fig. 1) for selected river stations.



a) b) c)

Fig. 1 Danube River at station Reni:
a) average annual discharge Q_a (blue points), double 7-year moving averages (red line), long term trend tr (green line);
b) the combined periodograms of the average annual discharges, significant standardized frequencies;
c) the auto-correlograms of the average annual discharges of the time series of the selected stations (time lag in years).

Conclusion

The spectral and auto-correlation analysis shows that the yearly discharge series include cyclic components, which are to be removed from the time series before the analysis of the long-term trends. The significant cycles are 2.4; 3.6; 21-22 and 29 years. The length of the cycles of about 3.6 years, which was found in the flow rates, is probably related to the Southern Oscillation, expressed by the SO index. The length of cycles of about 2.47 years may be related to QBO oscillation. The length of the cycles of about 14 years is related to the North Atlantic Oscillation, expressed by the NAO index. It follows that both the NAO and the SO phenomenon have an effect on the course of runoff fluctuations in the Danube basin.
These results have been included into the long-term forecast of the runoff regime in the Danube River basin.

Acknowledgements

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References

Hurst, HE (1951) Long term storage capacity of reservoirs. *Trans. Am. Soc. Civ. Eng.*, **116**, 770–808.

Pekárová, P (2009) Multiannual runoff variability in the upper Danube region. DrSc. qualification degree thesis, Bratislava, IH SAS, http://pavla.pekarova.sk/doktorska-dizertacna-praca.

Small Scale Rivers and their impact on the Danube River Basin

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Introduction

The Danube River Basin, being Europe's second largest river basin, is subject to increasing pressure and serious threats of pollution from agriculture, industry, and cities. The Drava River is the fourth largest Danube tributary. Only 17 % of the total area of the Drava catchment is located in Croatia, but during its flow through Croatia, it receives waters from a couple of significant tributaries, such as Plitvica, Bednja and Mura (National institute, 2014; Liska, 2015).
In such a vast catchment, as is the Danube catchment, smaller streams and rivers sometimes seem to be overlooked. But if one considers the fact that they make up 70 %–80 % of the total channel length of larger river networks, and they greatly influence downstream sections of these networks, in depth knowledge of the smaller streams and rivers characteristics is very important. They also play a significant part in retaining or transmitting both sediments and nutrients while at the same time they are a home and migration corridor for various aquatic organisms (Wohl, 2017).
Climate changes and human activities cause changes of the hydrological regime within the Danube River Basin. This change can be observed in hydrological regime of the small streams and rivers, as well as consequently in a big rivers. The smaller rivers often have torrential flow and there is an imperative for analysis of their hydrological regime. The analysis will be performed on the real case study of river Plitvica in the northwestern part of Croatia.

Methodology

For the purpose of this study, the time series of average daily flows of the river Plitvica at available measurement stations are analyzed. This includes correlation analysis, as well as application of the Rescaled Adjusted Partial Sums (RAPS) method. Hydrogeological analysis also includes field prospection and a comparison with existing hydrogeological maps of the analyzed area.

Results

The river Plitvica flow has stochastic and torrential characteristics, which can be observed in Fig. 1.

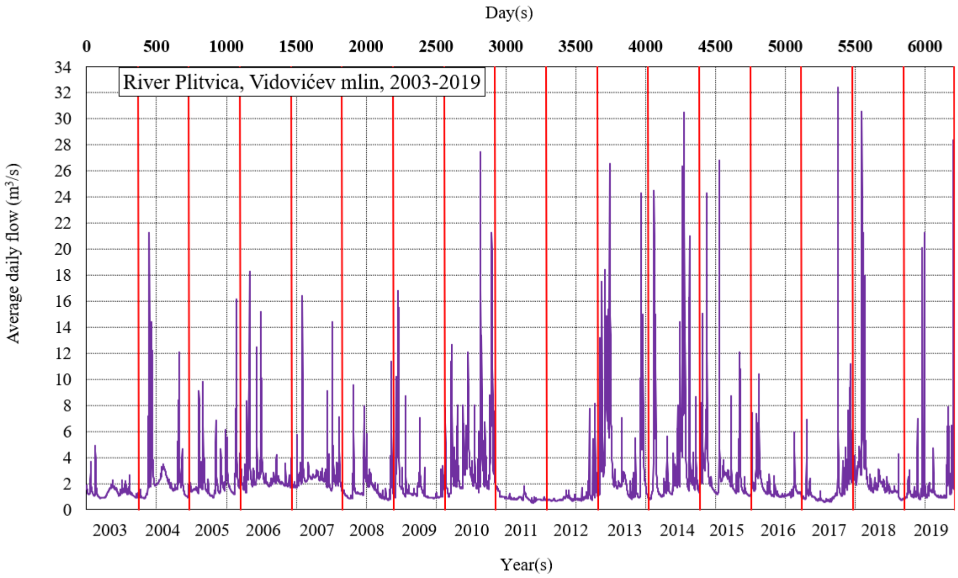

Fig. 1 Hydrogram of the river Plitvica for the years 2003-2019 (MHSC, 2020)

Changing of the hydrological regime could be seen on the Fig. 2. The river Plitvica is about 28,6 km long and is characterized by a pluvial regime which means that maximum flows are expected immediately after precipitations (Implementation plan, 2014).

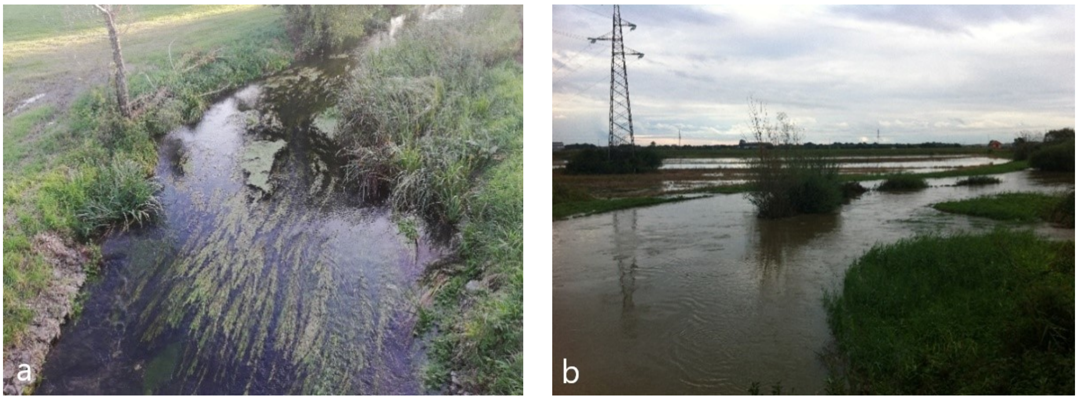

Fig. 2 Dry (a) and rain (b) regime of the river Plitvica

Conclusion

Since river Plitvica is a tributary of the river Drava, it is necessary to thoroughly research and explanation such changes in the water regime. An in-depth research is planned, which will primarily determine and quantify connections between precipitation and river flow, and after this to consider impact of the hydrogeological properties of the river Plitvica catchment.

References

Croatian Meteorological and Hydrological Service (CMHS). Daily flow for river Plitvica from 2003 till 2019; Croatian Meteorological and Hydrological Service (CMHS): Zagreb, Croatia, 2020.

Implementation Plan For Flood Defense of the Defended Area sector A - Mura And Gornja Drava. Defended Area 20 Area of Small Plitvica-Bednja Basin (2014), Available: https://www.voda.hr, Accessed: 20.2.2021.

Liska I (ed.) (2015). The Danube River Basin, Springer Berlin Heidelberg, 525 pp.

National Institute for Environment and Department of Water Resources Management Miklos Szalay with support by Alexander Zinke (2014). Preparation of the Drava River Framework – Analysis of the International Drava River Corridor – Joint Drava river corridor analysis report.66 pp.

Wohl E (2017). The significance of small streams, *Frontiers of Earth Science*, **11** (3), 447–456.

Low Flow Analysis of the Drava River

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Abstract

Low-flow periods are considered equally critical from both water management and ecological perspectives. According to catchments' hydrological and physical features, levels of resilience to both extremes–floods and low-flow periods (or hydrological droughts) can be different. Low-flow episodes are very difficult to recognize owing to the ambiguous definition of 'low flow'. Several indices have been recommended; the most frequently used ones include those obtained from low-flow statistics and the standardized streamflow index (SSI). Level of catchment resilience also depends on anthropogenic impacts over a longer time period. Also it usually has seasonal character. According to (Soto, 2020), studies on streamflow trends (on an annual or seasonal basis) have become a fundamental question in hydrological research in recent years. In addition, a pan-European study on a dataset of more than 600 daily streamflow records was analyzed to detect spatial and temporal changes in streamflow droughts. In most catchments, there were no significant changes, but distinct regional differences were found in all time periods (Hisdal, 2001). Hydrological analysis of hydrological regime of the Danube River and its tributaries projected considerable changes of seasonal stream-flow in the next 30 years (Stagl, 2020). The Drava River water regime also has been studied and results showed increasing of upstream mean annual discharge variabilities due to significant precipitation variability and decreasing of downstream mean annual discharge variabilities (Gajić-Čapka, 2010).

The most common low-flow indices are the mean flow, coefficient of variation in the annual mean flow, flow-duration curve, annual minimum flows, streamflow deficit durations, streamflow deficit volumes, recession indices. In this paper, an analysis of proposed low-flow indices is presented, based on daily discharges from 1962 to 2019 measured on two hydrological stations of the Drava River in Croatia (Table 1). The section between these two hydrological stations is the most endangered by hydrological drought (Tadić, 2019).

Table 1 Basic hydrological data of analyzed sub-catchments

Hydrological station	Distance from the confluence (rkm)	Catchment area (x103 km^2)	Available date series of water level	Available date series of daily discharges
Terezino Polje	152.3	33.9	1925–2019	1962–2019
Donji Miholjac	80.6	37.1	1926–2019	1962–2019

The analyzed area has a typical lowland catchment characterized by a mild slope, pronounced river meandering, and alluvial soil with dominant agricultural fields, lately very often facing water deficit during vegetation period. The water regime of the Drava River is pluvial-glacial, characterized by low water content in winter, and high in late spring and in the first half of summer. The mean flow of the analyzed fifty-seven-year period for the hydrological station Terezino Polje is 517,13 m^3/s, while for Donji Miholjac it is slightly higher 531.18 m^3/s. Figure 1 presents minimum annual and seasonal discharges of both hydrological stations.

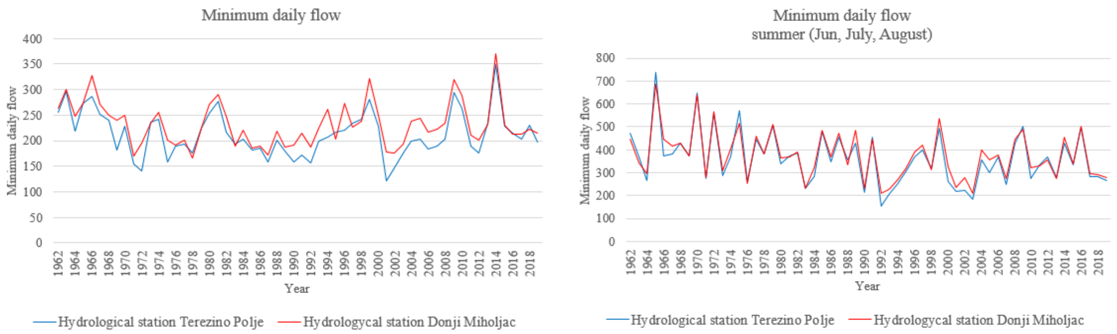

Fig.1 Minimum daily flows of the hydrological station Donji Miholjac and Terezino polje from 1962 to 2019

The hydrological stations Terezino Polje and Donji Miholjac are about 50 kilometers apart, so there are no significant differences in the course of the minimum daily flows. During the summer months, the decrease in the value of minimum daily flows is most pronounced, and further analysis of the data leads to the conclusion that the descending trend for both stations in the summer period is statistically significant. The negative trend during the summer months (June, July, August) of the hydrological station Donji Miholjac is also shown by the Sen's slope (Figure 2).

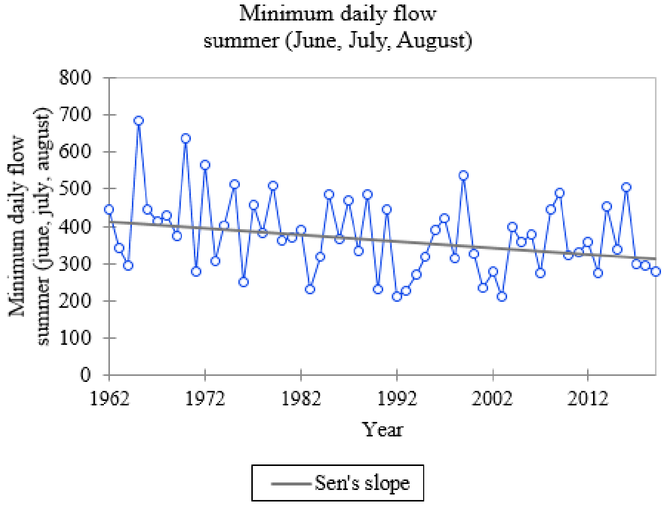

Fig.2 Sen's slope of minimum daily flows in the summer period – hydrological station Donji Miholjac

References

Gajić-Čapka M,Cesarec K (2010) Trend i varijabilnost protoka i klimatskih veličina u slivu rijeke Drave, *Hrvatske vode*, **18** (71); s. 19–30.

Hisdal H, Stahl K, Tallaksen, LM, Demuth, S (2001) Have streamflow droughts in Europe become more sever or frequent? *International Journal of Climatology*, **21**, 317–333.

Soto B (2020) Trends of hydrograph components in rivers of North of Iberian Peninsula during 1972–2012, *Environmental Earth Sciences*, **79**: 16, https://doi.org/10.1007/s12665-019-8761-7

Stagl JC, Hattermann FF (2020) Impacts of Climate Change on the Hydrological Regime of the Danube River and Its Tributaries Using an Ensemble of Climate Scenarios, *Water 2015*, **7** (11), s. 6139–6172.

Tadić L, Brleković T (2019) Hydrological Characteristics of the Drava River in Croatia, In: Lóczy D. (eds) The Drava River. Springer Geography. Springer, Cham. https://doi.org/10.1007/978-3-319-92816-6_6

Long-term tendencies and annual distribution of water regime, suspended sediments and mineralization of the Low Danube within the Ukrainian part

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Introduction

This investigation aims at studying the individual components of the hydrological and hydrochemical regimes of the Low Danube River (within Ukraine) in connection with the widespread use of the river's water for water supply and irrigation in the southern region, as well as to ensure more effective regulation of water-salt regime of the Danube lakes using the Danube River as a main source for their water renewal. One of important aspects includes the study of the regime of the Danube River's suspended sediments brought to its delta due to their impact on the formation of the delta at the river's mouth of as well as due to the impact on siltation of deltaic and pre-delta lakes and canals connecting the lakes with the Danube River (Hydrology of the Danube Delta, 2004).

The analysis of the current state of the hydrological regime in the Lower Danube shows that natural and anthropogenic changes which affecting the water discharge should be considered separately.

Anthropogenic factors are mainly related to hydraulic engineering structures which have been actively implemented since the 1960s and led to the regulation of the Danube River runoff (Best, 2019). Such structures caused a redistribution of the long-term runoff of the Danube River across its delta (Kiliya and Tulcea branches) with the increase of water content in the Romanian part of the delta (Tulcea branch) and its decrease in the Ukrainian part (Kiliya branch) (Cheroy, 2013).

The impact of climate change on the water regime of the rivers of the Danube Countries (especially in the territory of Ukraine) has been manifesting itself over the last thirty years of the retrospective period (Pekárová et al., 2019). The paper (Grebin, 2010) considers 1989 to be a turning point in terms of the air temperature change in Ukraine and, accordingly, the rivers' hydrological regime change.

The purpose of the work is to study long-term and current trends related to changes in hydrological (water levels and discharges, suspended sediments runoff) and hydrochemical (mineralization) regimes of the Danube River within the Ukrainian interval from Reni to Ismail, internal annual distribution of water runoff, as well as suspended sediments runoff and mineralization during the years of varying water content.

Methodology

The statistical and mathematical methods were used to assess the characteristics of the long-term hydrological regime of the Lower Danube. The F-test (Fisher criterion) was used to assess the statistical homogeneity of the initial information. The assessment of cyclical fluctuations of river runoff was performed using the residual mass curves. Statistic parameters are calculated via the method of moments and the method of maximum likelihood.

Results

Thus, the verification of the homogeneity of time series of average annual, maximum and minimum water discharges was performed for different periods of water content of the Lower Danube. Such periods include the natural regime of river runoff (1840–1920), the least altered river runoff regime (1921–1960) and the most altered river runoff regime under the anthropogenic influence (1961–1989). The determination of climate change impact on the Lower Danube River allowed introduction of a new, present period of its hydrological regime (1990–2015) (Romanova et al., 2019).

According to F-test (at the significance level of 5%) time series of average annual water discharges at Reni and Ismail water gauge station (WGS) should be considered as uniform, i.e. the influence of anthropogenic factors and climatic change did not have a major impact on the annual river runoff of the Danube Delta as a whole. However, if we consider the different phases of water content separately, there are still some changes. For instance, the lack of uniformity of the time series of the maximum and minimum discharges may be observed over the period when hydraulic engineering

structures started to affect the river's hydrological regime (in 1961). At the same time, the influence of climatic changes on the river runoff in the late 1980s didn't have any influence on the time series of such water discharges.
Although the annual runoff series proved to be homogeneous in time, the analysis of the aggregate multi-year series (1840–2015, i.e. over the period of 176 years) of the Danube River average annual water discharges across its length from Reni to Ismail indicated the presence of a weakly expressed, almost two centuries long trend towards their increase.
The authors also performed the analysis of the cyclicity and uniformity of the annual water discharges in the course of time over different periods of the Lower Danube water content. The period of conventionally natural river runoff regime (1840–1910) may be considered as the one that has a negative trend, whereas the period of the least altered runoff regime (up to the 1960s) has a neutral trend. Over the period from the 60s to 80s of the last century (i.e. over the period of the most altered runoff regime and before the significant impact of climatic changes) a positive trend was observed. The period after 1989 (the period of significant climatic changes) had a trend towards a certain decrease of the annual river runoff up to 1994 and a slow increase (starting from 1995) of the annual river runoff across the lower course of the Danube River.
The study of long-term variation of maximum water discharges over the period of 1921–2015 showed that the maximum water discharges featured a slight increase. It should be also noted that the time series of observations are characterized by the period with negative trend (1921–1960) and the period with positive trend (1961–2015) of the maximum water discharge. In addition, the period of climatic changes (after 1989) is also characterized by a less intensive growth of maximum water discharges.
The construction of chronological charts of the minimum water discharges across the Danube River from Reni to Ismail allowed the identification of insignificant positive trends and synchronicity of their course over the interim period for both of the WGS. However, since the 2000s such synchronous trend was disrupted due to the redistribution of water discharge between the Danube Delta branches.
It was also established that the intra-annual course of average monthly water discharges of the Danube River at Reni and Ismail river sections during the high-water, middle-water and low-water years (for the combined series of data from 1960 to 2015) was characterized by the homogeneity of river runoff depending on the water content of a certain season.
The study shows the presence of a pronounced trend to reduction of suspended sediments runoff of the Danube River at Reni (for the period of 1840–2015), with their most intensive decrease over the period of 1990–2015. Annual distribution of average monthly suspended sediments runoff of the Danube River for the years with typical water content (for the period of 1978–2015) showed that they have seasonal fluctuations. At the same time, there is a decrease in the suspended sediments runoff along the length of the river from Reni to Ismail. The long-term course of average annual mineralization values of the Danube River at Ismail (1981–2015) is characterized by their decrease against the background of a small increase in average annual discharges. As per the annual distribution of mineralization values associated with all water content groups there are the periods related to the phases of the river's yearly water regime during and the economic use of water (Shakirzanova et al., 2020).
Conclusion. Thus, the increase in the long-term period of the Danube River runoff within the interval from Reni to Ismail will contribute to the development of the region's economy and water supply, irrigated farming, regulation of the Danube Lakes filling with weakly mineralized river water. At the same time, the reduction of the suspended sediments runoff will restrain the siltation of the inlet canals connecting the lakes with the Danube River, which will improve the water renewal of the lakes with the river's fresh waters.

References

Best J (2019) Anthropogenic stresses on the world's big rivers, *Nature Geoscience*, **12**, 7–21 DOI:10.1038/S41561-018-0262-X

Cheroy OI (2013) The redistribution of runoff on the branches of the Danube Delta in terms of the existence of navigation channels, *Ukrainian Hydrometeorological Journal*, **13**, 176–182 (in Ukrainian)

Grebin VV (2010) Modern water regime of the rivers of Ukraine (landscape and hydrological analysis), Kyiv, Nika-Tsentr, 316 pp. (in Ukrainian)

Hydrology of the Danube Delta, Mikhailov VN (Ed.) (2004), Moscow, GEOS edition, 448 pp.

Pekárová P, Miklánek P (eds.) (2019) Flood regime of rivers in the Danube River basin. Follow-up volume IX of the Regional Co-operation of the Danube Countries in IHP UNESCO. IH SAS, Bratislava, 215 pp. + 527 p. app., https://doi:10.31577/2019.9788089139460

Romanova Y, Shakirzanova Zh, Ovcharuk V et al. (2019) Temporal variation of water discharges in the lower course of the Danube River across the area from Reni to Izmail under the influence of natural and anthropogenic factors, *Energetika*, **65**, 144–160. https://doi.org/10.6001/energetika.v65i2-3.4108

Shakirzanova ZR, Kichuk NS, Romanova YO, Kichuk ID, & Medvedieva IuS (2020) Research of individual components of hydrological and hydrochemical regimes of the Danube River within the Ukrainian interval from Reni to Izmail, *Ukrainian Hydrometeorological Journal*, **26**, 102–115. https://doi.org/10.31481/uhmj.26.2020.09

Estimation of spatio-temporal variability of the minimum water runoff of rivers in the Prut Basin (within Ukraine)

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Introduction

Minimal runoff and droughts are insufficiently studied in the Prut Basin. The reason for this is the river flood regime and the lack of groundwater runoff monitoring data. The main attention is paid to the study of the maximum runoff of rivers and floods. However, given current climate change, it is important to study the minimum runoff of water, as it may primarily respond to the onset of drought in the basin. This affects the water supply of cities, the operation of micropower plants in the basin, the concentration of pollutants in the water, etc. The results of the work will be useful for developing a drought management plan and river basin management plan as a whole.

Methodology

The minimum river runoff is a constant part of the runoff, which is usually maintained between precipitation events. The main calculated characteristic is the average minimum water flow for 7 days with the lowest water flow. The reason for choosing the 7-day period was physical and geographical features of the river basin, comparative flow and precipitation graph (the maximum period without precipitation was 7 days), research by American scientists on similar rivers.

Summer-autumn and winter periods were studied separately. We calculated water runoff modules to map the units. To study the minimum runoff, we used the initial data in the form of daily water flow from the beginning of observations at hydrological stations until 2018.

Standardized precipitation indices (SPI) and runoff indices (SRI) were used as indicators of drought. To determine SPI were used data from meteorological stations located in the study area. At this stage of our study, we used data only from observation points located within Ukraine.

Statistical correlations were used in the study, the presence and significance of the relationship between the values was determined based on the significance of the correlation coefficient (R) in accordance with the guidelines (Lukianets, 2010).

Results

During this work, maps of the distribution of 7-day minimum water runoff modules were created in order to analyze the spatial distribution of the minimum water runoff and obtain information on areas without observations. Data for interpolation were taken from 12 hydrological posts in the Prut and Siret basins, and from neighboring posts in the Tisza basin. The series of observations were longer than 30 years, the integrated curves showed that the data cover at least one hydrological cycle in each row; all series of observations are homogeneous.

Figure 1 shows the spatial distribution of the modules of the minimum winter runoff. We can see a decrease of minimum water flow modules in the direction from west to northeast and a parallel decrease in the density of the distribution of isolines. The distribution of the minimum summer runoff differs only by about 1.5 times the density of isolines and the values of the modules. In addition, it coincides with the average and maximum runoff. Precipitation amounts and changes in the orography of the region have a similar form of spatial distribution, confirmed by a good correlation. The values taken from the maps are reliable (Surai et al., 2020).

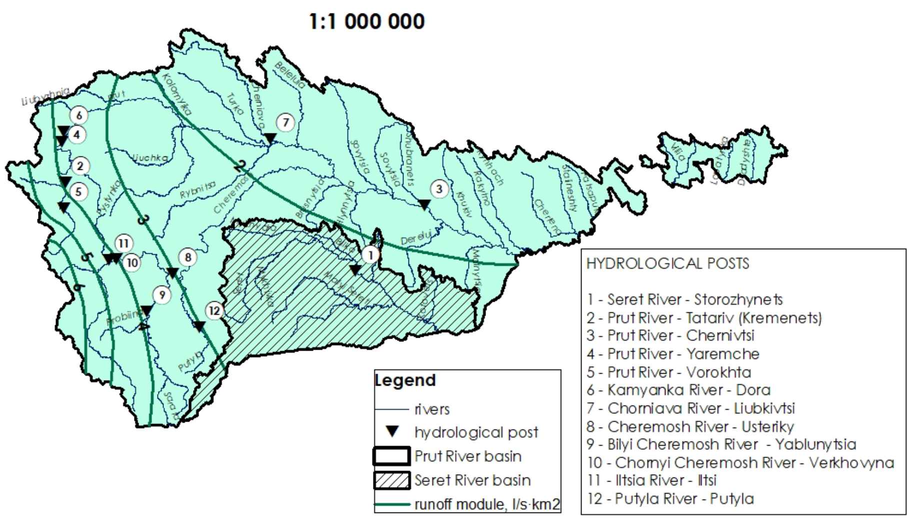

Fig. 1. Spatial distribution of modules of 7-day minimum runoff of winter periods of low flow (between floods) in the Prut and Siret basins

Correlation matrices were created separately for SPI and SRI to determine the relationships between the intensity of different types of droughts, to trace their spatial relationships and to compare them, determine the correlation between those two indices and with minimal water runoff. The reference points are hydrological posts located on the Prut River, which conditionally correspond to the change in the nature of the territory from mountain (Vorokhta and Yaremche) to plain (Chernivtsi).

SPI and SRI are strongly related, R is in the range of 0.86 - 0.60 at all points, which indicates a good relationship. In mountainous areas, taking a long-term retrospective, we can observe a slight delay in the reduction of the minimum runoff values in relation to the cases of decreasing precipitation. In the plains, the response of minimal runoff to meteorological droughts is faster due to a significant increase in the role of precipitation in the supply of rivers.

The need for further use of both indices is confirmed in the analysis of the most spatially widespread droughts of 1990 and 2015. In 1990, meteorological drought indices were lower than hydrological droughts, and relationships were better observed in small rivers. However, during the large-scale drought of the warm period of 2015, the meteorological drought index indicated an extreme drought in Chernivtsi, but the hydrological drought was moderate. Moreover, this despite the long period of air and soil drought before (Grebin V. et al, 2015). This means that the minimum runoff in winter respond better to weather droughts than summer ones. Nevertheless, the values of SRI are better correlated with the value of the minimum runoff, regardless of the season.

Conclusion

The created maps of the distribution of the minimum runoff modules are reliable and can be used for the areas of the Prut basin with no stationary observations. This is confirmed by the closeness of correlations between different series and characteristics, which indicates homogeneous conditions for the formation of minimal runoff and drought in the study area.

Comparison of changes in the characteristics of minimum runoff with SPI and SRI showed that periods of minimum water flow respond well to droughts within the studied basins, scilicet could be indicators of hydrological droughts. Meteorological droughts affect the flow of rivers in mountainous areas more quickly than in the plains, but are slightly behind the cases of hydrological droughts. Therefore, the minimum runoff of a given region can be estimated as an indicator of droughts, and an estimate of historical meteorological droughts can be used to predict future minimum runoff.

References

Grebin V.V, Boiko V.M, Adamenko T.I. Hydrological drought in 2015 in Ukraine: reasons of the formation, course and possible consequences. *Hydrology, Hydrochemistry and Hydroecology*. 2015. № **3** (38). – 115 p.

Lukianets O.I. Methodical instructions for the implementation of practical work in the discipline "Mathematical methods in hydrometeorology" for students of the Faculty of Geography. Kyiv. 2010. – 30 p.

Surai K.S., Obodovskyi O.G., Pochaevets O.O. Spatial distribution of minimum river runoff in the Prut and Siret basins (within Ukraine). *Hydrology, Hydrochemistry and Hydroecology*. 2020. № **3** (58). – 80 p.

Comparison of one- and two-dimensional models for flood mapping in urban environments

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Introduction

Floods are natural phenomena as a result of a combination of natural, geological and anthropogenic factors. Every year, floods cause loss of life, economic losses, adverse effects on the environment and cultural heritage all over the world. The 'Floods Directive' 2007/60 / CE by the European Parliament requires all Member States shall prepare flood hazard maps according to the three scenarios: (a) floods with a low probability; (b) floods with a medium probability ;(c) floods with a high probability. For each scenario the flood extent, water depths or water level and the flow velocity should be shown. To assess this, complete analyses of the watershed hydraulics based on one, two or even three-dimensional modeling are needed.
This paper presents a comparative analysis of the performance of 1D and 2D modelling of floods in urban area (Fig.1) with respect to the generation of inundation for flood events with 20, 100 and 1000-year return periods. The 1D analysis and 2D modelling are performed using the software HEC-RAS.

Fig. 1 Location of the study area (part of the town of Smolyan, Bulgaria)

Methodology

Traditionally one-dimensional (1D) approache is used for fluvial flood modeling where the river and the surrounding floodplains are represented by a set of cross sections. Accurate flood modeling in the selected urban area was performed using HEC-RAS 2D with diffusion wave (DW) approximation (Horritt et al., 2002). The computational mesh for terrain representation is 2,5 m. Detailed terrain data for mesh generation in the 2D model was provided by Drone. The upstream boundary conditions were performed by synthetic hydrographs calculated using Socolovsky method (Соколовски, 1959). For the downstream boundary condition normal depth was assumed. Land use data and aerial photographs from Drone were analysed in order to get reasonable Manning's n values.

Results

Comparison of HEC RAS 1D and 2D model results
Flooded area - There is a significant difference in the scope of the flooded areas. The extent of the flood in the 2D simulation is larger and more detailed due to the more detailed terrain data and the bathymetry of the river (Fig. 2).

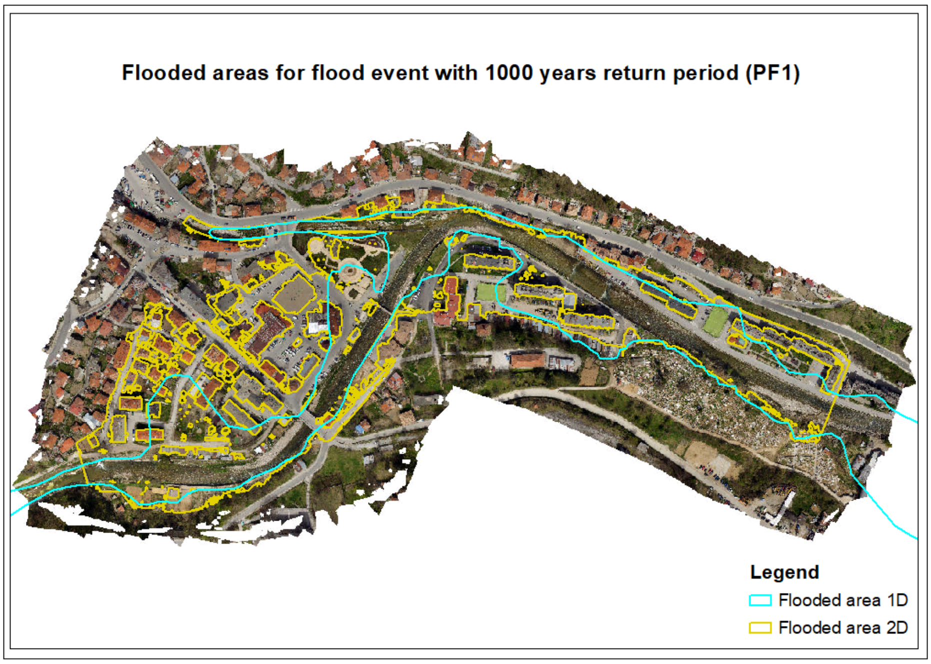

Fig. 2 Flooded areas for flood event with 1000 years return period (PF1) (на картата сложи само легенда с – за зелената линия flooded area 1D– за синята - flooded area 2D

Water level

Comparing the results from using 1D and 2D models along the river shows the differences in the water levels between 1 cm to 83 cm and the larger differences are the result of a more accurate description of the river bed (fig. 3 a).

The water level in the 1D model is constant along the cross section, but in the 2D model results show variability in the water level across the section (fig. 3 b)

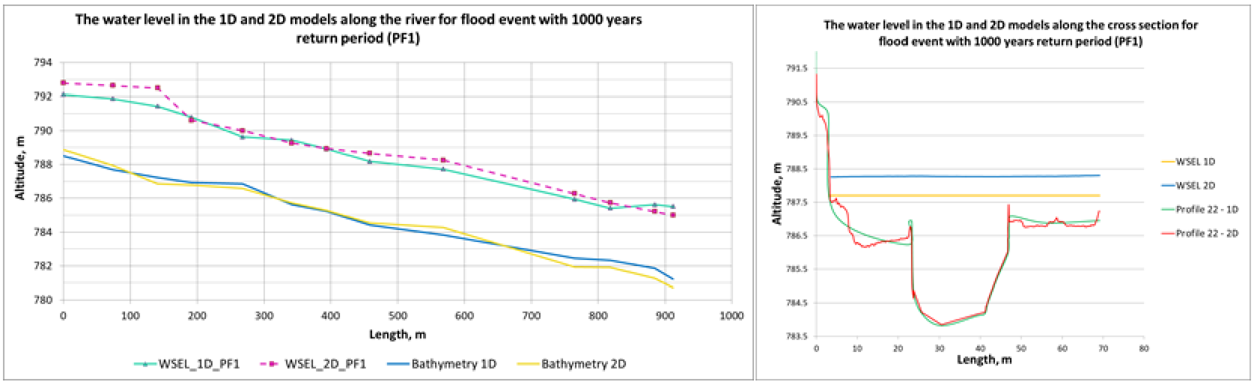

Fig. 3 Water level comparison 1D and 2D for flood event with 1000 years return period (PF1)

Conclusion

There is a similarity between the results of the two models in terms of the extent of the flooded areas.

The 2D model takes into consideration variation in ground geometry because it computes all hydraulic properties at each mesh cell and compute the water surface elevation at each cell. While the 1D model just computes WSEL at crosssections and between them uses the interpolation technique and does not take into consideration any changes in the characteristics of the river bed.

References

Horritt, M. S., & Bates, P. D. (2002). Evaluation of 1D and 2D numerical models for predicting river flood inundation. *Journal of hydrology*, **268**(1-4), 87–99.

Д. Соколовски, РЕЧНИЙ СТОК, Гидроме теорологическое издателство, Ленинград, 1959

Hydromorphology assessment of certain Slovenian rivers

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Introduction

Assessment of hydromorpolohical elements is a part of the evaluation of rivers' ecological status. The modification of hydromorphological characteristics of rivers is a crucial reason for not achieving good ecological status of river water bodies. According to Water Directive (Water Framework Directive, 2000) the assessment is based on the principles of sustainable development and sustainable spatial planning.

Methodology

The assessment of the hydromorphological condition of a river is obtained based on several indicators of hydromorphological elements, which according to the Water Directive include the hydrological regime, continuity of water flow and sediments and also morphological conditions of the riverbed, riverbank, coastal belt and riparian zone. Monitoring of hydromorphological elements uses spatial data and data from available databases, as well as data collected by field mapping in individual sections of the river. The use of the correct methodology for assessment by professionals requires precision in distance measurements and a sense of orientation on the field, where, in addition to cartographic backgrounds and aerial imagery, many modern devices, such as GPS receivers, mobile GIS applications and others, can be used. The use of such devices enables subsequent laboratory testing of field data and optimized and efficiently processing of data with computer programs. The basic monitoring unit is the 500-meters long reach unit. Overall assessment of the river hydromorphological elements modification in the reach unit is obtained by calculating the hydromorphological change index and the hydromorphological quality index.

Results and conclusions

Three rivers in the Danubian River Basin: Kolpa, Mura and Meža were included in the assessment of hydromorpolohical elements. Their ecological status is different, from high to good and moderate status. From the result of our research is well seen how the modification of morphological elements has a great influence on biological and hydrological elements, and on the chemical status of the river.

Knowledge of the rivers hydromorphological characteristics is one of the essential components of determining the degree of the ecological status of a river sections and water bodies. Identification of changes in water bodies through hydromorphological elements is necessary to determine measures for the revitalization of river. Modern river management envisages maintaining the natural state of the river or at least reducing the anthropogenically altered hydromorphological state of the river section. The assessment of the rivers hydromorphological modification should be carried out under the applicable methodologies for determining the ecological status of waters.

References

Brečko Grubar, V., Kovačič, G. (2019). Preizkus metodologije določanja hidromorfoloških lastnosti rek na primeru Nadiže, *Geografski vestnik*, **91**-1, s. 117–135.

goMURra. https://www.gomurra.eu/sl/aktualno/delavnica-o-ocenjevanju-hidromorfoloskega-stanja-mejne-mure/

Ulaga, F. 2018: Ekološko stanje slovenskih rek. Hidromorfološki elementi kakovosti. http://www.arso.gov.si/vode.si/novice/datoteke/035460-Ekolo%C5%A1ko%20stanje%20slovenskih%20rek_hidromorfologija.pdf

Ulaga, F. (2017). Spremljanje motnosti rek za ustreznejše vrednotenje kakovostnega stanja površinskih voda. *Ujma,* **31**, 196–201.

Water Framework Directive (WFD), Directive 2000/60/EC of the European Parliament and of the Council establishing a framework for the Community action in the field of water policy.

The climate change in the Ukrainian part of the Danube River basin and its possible impact on the river runoff

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Introduction

The impact of climate change on the river runoff is a very popular issue of scientific studies. This change is caused by many factors, in particular, air temperature, the amount of precipitation, evaporation, etc. The main goal of this study is to specify the changes in river runoff in the Ukrainian part of the Danube River basin and the role of different factors impacting on these changes.
Methodology
The data for period 1961–2019 of climatic parameters and water runoff in the Ukrainian part of the Danube River basin were analyzed. The features of water runoff of the rivers, located in the Ukrainian Carpathians, were studied. In many cases the data for the periods of 1961–1990 and 1991–2019 were analyzed separately. Correlation and regression analysis were used in the study. To determine the spatio-temporal fluctuations of the precipitation and water runoff the residual mass curves were drawn. The data on evaporation from the basin with water surface 20 m^2, located in Bolgrad town on the south of Odeska oblast, were gathered and treated. Based on the remote sensing technology, the water area of lakes, located on the left bank of the Lower Danube River, was specified. The long-term changes of evaporation from water area were calculated.

Results

The Ukrainian part of the Danube basin consists of two parts. One of them is located in the Carpathian Mountains and the surrounding area, the other one (plain) in the southern part of Odessa oblast. The water runoff in the mountainous part is incomparably greater than it is in the southern part.
The available data, obtained from meteorological stations, located in the Carpathian Mountains, show the presence of the vivid tendency of air temperature increase. During 1961–2019 the increase in mean air temperature is about 2 °C. The changes in annual precipitation are not essential. These changes are of a cycle nature with the period of about 30 years. It is likely that modern dry phase will continues till the mid-2020s. The seasonal changes in the precipitation are rather small. Probably there is a small increase during cold period from September till March. In turn the precipitation in summer time is characterized with a tendency to decrease, primarily in June. Nowadays it is observed the increase of snow cover depth on the tops of the mountains. There is a vivid tendency of wind speed decrease, which is the most obvious in the second part of an year.
In spite of some changes in the climatic parameters the annual water runoff in the mountain part of water basin has not changed essentially. Similar to the changes in precipitation, it is of a cyclic nature. Nowadays it is observed the phase of relative small water runoff, which started in 2011.
The calculated evaporation, based on the water balance, shows up the cyclic nature of this phenomenon, but the duration of the cycles is larger, than for precipitation and water runoff. The available data indicate that the increase in evaporation has been lasting for about 40 years.
The water runoff of the rivers, located at high altitudes, has the tendency to increase in cold period. In turn the common feature of the rivers, primarily located in low-mountain terrain, is the decrease in water discharge in the period from May till August.
The available data on evaporation from the water surface in the lower and simultaneous southern part of the Danube River basin show rather close non-linear relationship between evaporation and air temperature. The increase of air temperature caused the essential increase of evaporation from the water surface. Currently, the volume of evaporation from the water bodies below the mouth of the Prut River exceeds the water flow of the local tributaries of the Danube River.

Conclusion

In spite of some changes in the climatic parameters the annual water runoff on the Ukrainian part of the Danube River basin has not changed essentially. Similar to the changes in precipitation, it is of a cyclic nature. Nowadays the phase of relative small water runoff, which started in 2011, is observed.
The calculated evaporation, based on the water balance, shows its increase. The increase of air temperature causes the essential increase of evaporation from the water surface.

References

Didovets L, Krysanova V, Bürgera G et al (2019) Climate change impact on regional floods in the Carpathian region. *Journal of Hydrology: Regional Studies*, **22**, 1–14.

Duethmann D, Blösch G (2018) Why has catchment evaporation increased in the past 40 years? A data-based study in Austria. *Hydrol. Earth Syst. Sci.*, **22**, 5143–5158.

Fendekova M, Gauster T, Labudova L et al (2018) Analysing 21st century meteorological and hydrological drought events in Slovakia. *J. Hydrol. Hydromech*., **66**, 2018, 4, 393–403.

Gorbachova L, Zabolotnia T, Khrystyuk B (2018) Homogeneity and stationarity analysis of the snow-rain floods in the Danube Basin within Ukraine. *Acta Hydrologica Slowaca*. **19**, 1, 35–41.

Halmová D, Pekárová P (2020) Runoff regime changes in the Slovak Danube River tributaries. *Acta Hydrologica Slovaca*. **21**, 1, 2020, 9–18.

Lukianets O, Obodovskyi O, Grebin V, Pochaievets O (2019) Time series analysis and forecast estimates of the mean annual water runoff of rivers in of the Prut and Siret basins (within Ukraine). Electronic book with full papers from XXVIII Conference of the Danubian Countries on Hydrological Forecasting and Hydrological Bases of Water Management, Kyiv, 133–139.

Mostowik K, Siwek J, Kisiel M et al (2019) Runoff trends in a changing climate in the Eastern Carpathians (Bieszczady Mountains, Poland). Catena, 182.

Obodovskyi O, Lukianets O (2017) Patterns and forecast of long-term cyclical fluctuations of the water runoff of Ukrainian Carpathians rivers. *Research, Engineering & Management*. **73**, 1, 33–47.

Spinoni J, Szalai S, Szentimrey T et al (2015) Climate of the Carpathian Region in the period 1961–2010: climatologies and trends of 10 variables. Int. J. Climatol. 35: s. 1322–1341.

Stagl JC, Hattermann FF et al (2015) Impacts of climate change on the hydrological regime of the Danube River and its tributaries using an ensemble of climate scenarios. *Water* **7** (11), 6139–6172.

Szolgay J, Blöschl G, Gribovszk Z, Parajka J et al (2020) Hydrology of the Carpathian Basin: interactions of climatic drivers and hydrological processes on local and regional scales – HydroCarpath Research. *J. Hydrol. Hydromech.*, **68**, 2, 128–133.

Vyshnevskyi V, Shevchuk S, Matiash T (2019) Water resourses of the Lower Danube River and their use within the territory of Ukraine. Electronic book with full papers from XXVIII Conference of the Danubian Countries on Hydrological Forecasting and Hydrological Bases of Water Management. Kyiv. 199–208.

Zabolotnia T, Gorbachova L, Khrystiuk B (2019) Estimation of the long-term cyclical fluctuations of snow-rain floods in the Danube basin within Ukraine. Meteorology, *Hydrology and Water Management.* **7**, 12. 3–9.

Topic 2

Current status of the hydrological basis of the Danube water management (gauge network and water ecosystem)

Hydrological modelling to investigate climate change as part of transboundary river sediment management: Case study of the Thaya River Basin Czech Republic

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Abstract

Water demand, ecology and sustainability of a river basin has been a very complex topic. As rivers form borders across many countries, the cross-border cooperation is an essential issue of their management and protection. This paper introduces a newly developed hydrological lumped water balance model on a daily time step basis and using climate change data constructed by the statistical downscaling tool LARS WG. The hydrological data under climate change will be represented using an ensemble of 9 climate scenarios simulations. The hydrology analysis of a climate change impact will be presented on the case study of the Thaya river basin in the cross-border area of Austria and the Czech Republic.

Introduction

Water demand, ecology, and sustainability of a river basin with a growing population has always been a very complex topic and under ongoing climate change, it is going to be more serious than ever before. As rivers form borders across many countries, access to water cause stress for inhabitants, the cross-border cooperation is an essential issue of their management and protection. From this point of view the international agreements and the cross-border cooperation is necessary. In Europe, the Danube affects the life of human communities in 19 European countries inside and outside the European Union (EU), roughly 81 million inhabitants. Thus, inside the EU the cooperation is framed by the Convention on the protection and the use of transboundary watercourses and international lakes (Council of the European Union, 1995), which is based on the agreement of the cross-border commissions. EU also supports the cross-border development via European funding.

The aim of the paper is to introduce the interim results of the Interreg project ATCZ28 Sediments, ecosystem services and interrelation with floods and droughts in the Austrian-Czech border region (SEDECO) which is based on a close bilateral cooperation and sharing the data about the Thaya river, a tributary of the Danube. The main outcome of SEDECO is to develop a sustainable river sediment management in the Austria and Czech cross-border part of the Thaya river basin. In order to map the river sediment balance, a new hydrological lumped water balance model of the Thaya river basin under climate change has been developed. For this paper, the control formulas of the water balance model were adapted to a different time scale, while the definition of an optimal calibration set up and climate change application were based on RCP's emission scenarios.

Methodology

The Study area is located in the cross-border region of Austria and the Czech Republic in Central Europe. The Thaya river basin area is 4 602 km^2. In the study area, there are 19 precipitations stations measuring precipitation, 11 meteorological stations measuring both temperature and precipitation and 8 hydrometric profiles measuring river flows in the catchment. There are four water reservoirs. For the purposes of the hydrological modelling, the area was divided into three subbasins: i) Thaya 1 basin, area 1 755 km^2, ii) Jevisovka basin, area 643 km^2 and iii) Thaya 2 basin, area 4 602 km^2. In this paper only the results of the hydrological modeling of Thaya 1 basin will be presented. The uniformly length of hydrologic data from the relevant stations were available from 1991 to 2018. The input data provided to the model by Austrian and Czech authorities was in a form of an air mean daily temperature T_d, total daily precipitations $H_{s,d}$ and a mean daily flow $Q_{d,h}$.

Lumped water balance model as a hydrological modelling tool is one of the bases of our method approach. The water balance model is based on the control formulas which specify a total daily flow and daily soil moisture. The control balance formulas are defined as a mean daily surface flow $q_{s,d}$, a mean daily groundwater discharge $q_{g,d}$ and mean daily evaporation E_d. The formulas were described by Wang et al (2014), Wang, Zhang, & Yang (2016) and for the conditions of central European hydrology and climate were adapted by Marton & Knoppová (2019). The main character of the formulas is changed from monthly to daily time step in this paper. Four parameters k_s, k_g, k_e, $S_{d,i-1}$ in the control formulas had to be calibrated. These coefficients were decision variables for model optimization. The objective function was to maximize the Nash–Sutcliffe model efficiency coefficient (NSE). Microsoft Excel was used for the initial testing. The Generalised Reduced Gradient algorithm (Landson et al, 1978) was used for the model optimization.

During calibration process, combinations of many model setups were tested. The percentage ratio between the calibration and validation data was 70/30 (1991–2009)/(2010–2018). The suitable number of meteorological and precipitation stations was tested. The optimal model setup was tested on 4 potential evapotranspiration methods. Four different sets of decision variables were used: i) 82 (two weeks per year + 1), ii) 157 (one week per year +1), iii) 367 (three days per year +1), iv) 1099 (1 day per year +1). Three different lack times flow vs. precipitation: i) day, ii) day-1 and iii) day-2 were tested.

The statistical downscaling was conducted to the hydrological model using LARS WG software (Racsko et al, 1991, and Semenov et al, 2013). Using LARS WG, a baseline data and the ensemble of 9 climate scenarios were created based on the boundary conditions of 4 Global Climate Models and 3 RCP's emission scenarios for two time periods PI (2021–2040) and PII (2041–2060).

Preliminary results

The optimal model set up was found for the calibration NSE = 0,443 and validation NSE = 0,221 using the Turc method of potential evapotranspiration, 8 stations applied to model, 82 variables (two weeks per year + 1) and day – 1 flow vs. precipitation lack time.

Water flow in the Thaya 1 basin decreased in PI from -5.8 % to -22.5 % against the baseline period; in PII decreased from -9.4 % to -28.5 % against the baseline period. In total, till 2060 the inflow will decrease by -8 % to -23.3 % against the baseline period. Generally, the preliminary results have shown a promising way to setup the water balance model in a daily time step and the way the model could be made more precise: use the different calibration/validation data as it is known that in period 2015 to 2019 it was an unusual extreme drought in the river basin; test the lack time in the ground water flow $q_{g,d}$,; setup the snow melt model extension; and use a different method of optimization. The results will be further used in SEDECO for the simulation of the reservoir system management, the cross-border sediment balance analysis, and as part of boundary condition of the hydraulic model of reservoir sedimentation. All this work will provide the first scientific foundation to coordinate a joint cross-border river and the reservoir sediment management in this area and to help to improve knowledge of the cross-border river basin management in a wider scale.

References

Council of the European Union. (1995). Council Decision of 24 July 1995 on the conclusion, on behalf of the Community, of the Convention on the protection and use of transboundary watercourses and international lakes (95/308/EC). Retrieved from https://eur-lex.europa.eu

Lasdon, L.S., Waren A.D., Jain A. & Ratner M. (1978). Design and testing of a generalized reduced gradient code for nonlinear programming. *ACM Transactions on Mathematical Software*, **4** (1), 34–50. doi:10.1145/355769.355773

Marton, D., & Knoppova K. (2019). Developing hydrological and reservoir models under deep uncertainty of climate change: robustness of water supply reservoir. Water Science and Technology: *Water Supply*, **19** (5), 1–11. doi.org/10.2166/ws.2019.102

Semenov, M.A., Pilkington-Bennet, S. & Calanca, P. (2013). Validation of ELPIS 1980-2010 baseline scenarios using the European Climate Assessment observed dataset. *Climate Research*, **51** (1), 1–9. doi:10.3354/cr01164

Racsko, P., Szeidl, L. & Semenov, M.A. (1991). A serial approach to local stochastic weather models. *Ecological Modelling*, **57** (1-2), 27–41. doi:10.1016/0304-3800(91)90053-4

Wang, G.Q., Zhang J. Y., Jin J.L., Liu Y.L., He R.M., Bao Z.X., Liu C.S., & Li Y. (2014). Regional calibration of a water balance model for estimating stream flow in ungauged areas of the Yellow River Basin. *Quaternary International*, **336**, 65–72. doi.org/10.1016/j.quaint.2013.08.051

Wang, G., Zhang J., & Yang Q. (2016). Attribution of Runoff Change for the Xinshui River Catchment on the Loess Plateau of China in a Changing Environment. *Water*, **8** (6), 267. doi.org/10.3390/w8060267

Changes in selected low-flow characteristics in period 2001–2015 compared with reference period 1961–2000 in Slovakia

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Introduction

This paper is a part of a broader study focused on the assessment of drought on surface watercourses in Slovakia, specifically on the part focused on the assessment of the flow distribution curves in the area of low-flows and the assessment of non-flow characteristics of drought. The outputs of these analyzes are important for water management, for example as a basis for setting ecological flow limits.

Methodology

We have selected representative water-gauging stations in Slovakia with period of observation at least since 1961 and with little or no human influence on discharges. For these stations, we have evaluated low-flow characteristics and their change in period 2001–2015 in comparison with 1961–2000 (reference period). The change was evaluated for selected percentiles (Q_{330d}, Q_{355d}, Q_{364d}) from flow duration curve (low-flow area) for each evaluated profile, as well as non-flow characteristics (number of days with discharge below selected threshold values, dates / seasons of longest low-flow periods, etc.).

We have calculated flow duration curves (FDC) by two methods:

1. The standard one (covered by the national Slovak Technical Standard STN 75 1410-1:2008, section 5.1.3) is based on mean daily discharge data series for the whole evaluated period sorted in descending order. Numerical values of the FDC are given for the average time durations, when the mean daily discharge was reached or exceeded. In Slovakia average durations are most commonly given as the number of days in the year; such a procedure can only be applied to a year and a multiannual period. The numerical discharge values of the crossing line corresponding to the selected durations in days (M) are referred to as M-day discharges (Q_{Md}) – e.g. the characteristic Q_{355d} is an often used limit in water resource management.
2. An alternative method (also mentioned in STN 75 1410-1:2008, section 5.1.9) is based on the calculation of FDCs for individual years of evaluated period. Subsequently, the FDC for the multiannual period is determined by calculating the averages of the discharge values from FDC of individual years, corresponding to the same values of M. Values calculated by this method were denoted as $Q_{Md,rr}$ in this contribution. This method brings higher values in the area of low-flows ($Q_{330d,rr}$, $Q_{355d,rr}$, $Q_{364d,rr}$), while in the area of higher discharges the differences between this alternative method and standard method are disappearing.

Results

Evaluation of data in selected water-gauging stations in the period 2001–2015 versus the reference period 1961–2000 by the standard method has shown a higher number of stations with a decrease of $Q_{330d,2001–2015}$ compared to $Q_{330d,1961-2000}$. An increase of values was prevailing in $Q_{355d,2001–2015}$ and $Q_{364d,2001–2015}$ against the corresponding reference values, with a more significant increase in Q_{364d} . The increase for all quantiles is noticeable especially in the area of northern parts of Middle and East Slovakia (upper parts of Váh, Hornád and Poprad river basins). The decline is noticeable in eastern Slovakia (Bodrog river basin) and in the South and West part of Slovakia. For Q_{364d} it is obvious, that the number of stations with increasing values significantly exceeds the number of stations where the value of Q_{364d} decreased in the evaluated period compared to the reference period. Results differ for the alternative method used in the contribution in comparison with the standard method. The number of stations with an increase of the values of the evaluated quantiles $Q_{Md,rr}$ in the evaluated period 2001–2015 compared to the reference period 1961–2000 prevails for all quantiles. For the Q_{364d} quantile, the increases in the evaluated period are more significant in the standard method of determination. The increase of values for all quantiles for the representative stations in comparison with the reference period is manifested mainly in eastern Slovakia in the Hornád, Slaná and Poprad river basins. The decrease in the values $Q_{330,2001–2015,rr}$ compared to $Q_{330,1961–2000,rr}$ is most numerous in the Morava and Váh river basins.

Next we have assessed the non-flow characteristics based on the number of days with mean daily discharge below the specified limits (selected Q_{Md} values) and then calculated averages per river basins. According to this analysis we can state that among the most sensitive river basins (with the highest number of dry days) for the lowest limits Q_{364d} and Q_{355d} were the Nitra and Bodva river basins. For the limits $Q_{364d,rr}$ and $Q_{355d,rr}$, the Morava, Nitra, Bodva and also Slaná (for $Q_{355d,rr}$) river basins were identified as most sensitive. According to the evaluation results, the choice of the limiting hydrological characteristic is of key importance for defining the low-flow periods. The subsequent analysis of the lengths of the low-flow periods in relation to the limit gives the necessary feedback to assess the suitability of the limit, e.g. as a limiting flow value for the purposes of abstraction permits while maintaining the flow in the stream for general water use and maintaining good ecological status.

Duration and seasonality of important dry periods were assessed based on the 5 longest low-flow periods in each evaluated profile for individual flow limit values as it is long periods of drought that are most serious in water management having significant negative economic impacts. The Nitra and Bodva river basins proved to be the most sensitive river basins (with the largest number of dry days) for the lowest limits – Q_{364d} and Q_{355d}. For the limits $Q_{364d,rr}$ and $Q_{355d,rr}$, the Morava and also Slaná (for $Q_{355d,rr}$) river basins were assigned to the Nitra and Bodva river basins. In the evaluated profiles, the occurrence of the longest low-flow periods in the summer-autumn period predominates in Slovakia, but the occurrence in the winter period, with an overlap into the spring months, is also significant (especially in higher mountain areas or in stations with higher altitudes). At higher values of flow limits, low-flow periods have a longer duration, a connection summer-autumn and winter low-water periods can occur.

Conclusion

The weakness of the standard method of determining the flow duration curves, especially in the area of low-flow, is that it allows the values of the smallest quantiles (Q_{364d}, Q_{355d}) to be influenced by a small number of long-lasting drought episodes (Blaškovičová et al., 2017). This is also supported by the analysis of non-flow characteristics, which showed that in the period 2001–2015 evaluated by the standard method the discharges in the part of stations did not fall at all under the Q_{364d} values determined by the standard method from the reference period. The alternative method eliminates the mentioned shortcoming of the standard method and from these two methods it probably has better precondition to be used as an input for determining the so-called ecological flows.

References

Blaškovičová L, Melová K, Poórová J (2017) Vplyv voľby limitných charakteristík na hodnotenie nedostatku vody v obdobiach malých vodností, Manažment povodí a extrémne hydrologické javy, Vedecká konferencia s medzinárodnou účasťou, 11. 10. 2017, Vyhne, Hotel Sitno

STN 75 1410-1:2008 Hydrológia. Hydrologické údaje povrchových vôd. Kvantifikácia priemernej vodnosti. Časť 1: Charakteristiky denných vodných stavov a prietokov (SK)

Water governance in transition

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Introduction

The basics of water policy, or formerly so-called water management, are based on principles that have been shaped over the centuries in the efforts of civilizations to adapt the water regime to their needs. The oldest, well-organized civilizations from Egypt, Mesopotamia, and ancient China manifested themselves with a good and systematic state administration capable of building and maintaining water systems. The entire community's well-being depended. Namely, water is not only the fundamental matter for our life, but it is also the basis of our economy. According to a UNESCO analysis (UNESCO, 2021), 78% of jobs are dependent on water. The issue of water is therefore very complex and scattered throughout all parts of society.

Characteristic of water management is the need for a long-term vision of development and significant investments, which require 5 to 10 years or more to perform. The consequences of building water systems have marked the area for centuries. Our watercourses look like thanks to the works carried out in the 19th and 20th centuries. In the water system, the changes are gradual, and nothing happens overnight, except when disasters occur.

In countries in transition from a socialist to a capitalist social order, water management has undergone radical changes. Some of them were positive, and some unfortunately negative. A significant reduction in the scope of hydrological measurements was observed, and a drastic reduction in funds for research and execution of works.

Methodology

The article is based on the author's fifty years of experience in solving water management problems in Slovenia and preparing lectures on water policy. The author has participated in the "Environmental Program for the Danube River Basin" as a member of the Task Force in developing The International Commission for the Protection of the Danube River (ICPDR), the UNESCO International Hydrological Program, and numerous international projects.

Water policy development in Slovenia

The development of water management before the transition is conditioned by cultural, economic, and political situations. In Slovenia, in the Austrian part of the Austro-Hungarian Monarchy, development was influenced by a strongly developed cooperative organization supported by other state institutions. Each region or country had its water law. Thus, the law on the waters of Kranjska (Herzogthum Krain,1872), for the most part, coded the formation and operation of water cooperatives organized for the drainage and use of water forces. Thus, the users of the water forces in Tržiška Bistrica took care of the reflection of watercourses and common facilities based on their rights. The decision-making vote depended on the right to use the energy potential, and the necessary funds were also collected in the same proportion. The state took care of the joint hydrological service, installing water meters, maintenance, collection, and publication of data. In performing public works, the Monarchy was extraordinarily well organized and very efficient. Austria has retained the basics of the organization of public works to this day. Similar developments took place in Croatia and BiH. In Slovenia, the law on waters was valid until the Second World War.

In the first years of the construction of the socialist state, works were carried out on large systems for the use of water power and the needs of agriculture. Namely, the period of the Second World War until 1950 was the driest period of the last century and covered the whole of Europe. Significant funds for the needs of agriculture, energy production, and works on the regulation of more significant watercourses were built with joint funds. In Slovenia, the national water management was very well organized after 1974 based on water management postulates (Vladisavljević, 1969, Grigg, 1996). Seven regional water communities with local self-government were formed under the leadership of water users, who also collected the necessary funds. Water management companies (VGP), one in each region, and a joint torrent management company (PUH) were in charge of the works. VGPs had planning, design, execution, and oversight services, where a conflict of interest was present. The system has its water management basics and long-term plans. The funds raised amounted to 1% of GDP. VGPs were strong construction companies with large capacities, so they competed extensively with other construction companies of low construction in the market with dumped prices.

In the transition to a new political system in the spontaneous process of privatization, water management has been reorganized in different ways in different ways and more or less experienced retardation in development. Thus,

funds for hydrological and other observations have been reduced, funds for system maintenance have been reduced, and investments are practically no longer carried out with domestic funds. The worst is the systematic destruction of archives and documentation. The political system of the so-called representative democracy is not capable of defining long-term lasting visions and developing water management or rather a water management. By water, we mean water management, which includes care for environmental processes related to the water regime, based on the water frame directive (WFD, 2000). Members of Parliament with a four-year term only accept projects that can be notified before the next elections. An EU-funded water supply project for the coastal region has been halted in Slovenia. When taking office, the Minister received a project approved by his predecessor, and what is worse, the project would be completed and put into operation after his mandate.
Politics is trying to solve problems, which are slowly piling up with political declarations. Thus, in the first law on environmental protection, water is defined as state property. The transfer of such a determination into practice is complicated. The Parliament determined that water deleted state property from the law at the first update of the law. Later, the Law on Waters envisages the establishment of the Water Council. Water councils were never formed, and Parliament removed them from the law after 16 years. In 2016, the Parliament introduced the right to drinking water in the Constitution of the Republic of Slovenia. The constitutional provision has not yet been transposed into laws and bylaws.

How to move forward – action more space for water

By regulating watercourses and draining land, civilizations have taken away water for their various needs since prehistoric times. One of the primary tasks of water management before the transition was to take away water space for agriculture and urbanization. In the transition and other countries in Europe with the so-called remediation and renaturation, water space is again taken away. The processes of change are slow, and the consequences are visible after many years. However, when it needs it, water takes up the space it needs, whether we like it or not. We note a sharp increase in flood damage.
In the Netherlands, Deltares carries out a comprehensive action on the waters called "More room for the river." By moving embankments, deepening and widening riverbeds, and other activities, water increases space, reduces the risk of floods, improves the ecological situation, and meets the needs of water users with the systematic involvement of stakeholders in decision-making. In 2013, the Slovenian National Committee for the International Hydrological Program UNESCO also launched a multi-water action.

References

Grigg, Niel, 1996, Water Resources Management: Principles, Regulations, and Cases, McGraw-Hill Professional;

Herzogthum Krain (1872), Landesgesetzblatt für das Herzogthum Krain ... Deželni zakonik za vojvodstvo ... - Google Knjige Available online: https://books.google.si/books/about/Landesgesetzblatt_für_das_Herzogthum_Kr.html?id=VinMxgEACAAJ&redir_esc=y (accessed on Jan 14, 2021).

UNESCO, (2021) The United Nations world water development report 2016: water and jobs - UNESCO Digital Library Available online: https://unesdoc.unesco.org/ark:/48223/pf0000243938 (accessed on Jan 14, 2021).

Vladisavljević, Živko, 1969, Osnove nauke o vodoprivredi (Fundamentals of water science). In O vodoprivredi, pogledi i metode (About water management, views and methods); Građevinski Fakultet Univerziteta u Beogradu, Unstitut za vodoprivedu "Jaroslav Černi": Beograd, 1969; p. 387.

WFD DIRECTIVE 2000/60/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL, of 23 October 2000 establishing a framework for Community action in the field of water policy; 2000;

Wikipedia, Room for the River (Netherlands) https://en.wikipedia.org/wiki/Room_for_the_River_(Netherlands)

Hydrochemical regime and water quality of the Danubian lake Katlabukh

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Introduction

The Danube lakes existed mainly due to the hydrology of the Danube. At the same time, their geographical location along the banks of the Danube had little effect on their historically established hydrochemical regime (Romanova et al, 2019). With the intensification of agriculture in the 1970s, additional use of the floodplains of the Danube began, and to protect them, embankment dams were built along the Danube, which radically changed the hydrological and historical water regime of the Danube Lakes. It is for this reason that the geographical location of Lake Katlabukh relative to other upstream lakes has created the conditions under which it has become hostage to the level regime of the Danube. Therefore, in recent decades, the filling of Lake Katlabukh in terms of its damping without forced water supply has significantly affected the deterioration of both the level regime of the lake and its hydrochemical condition.It is the reduction of water exchange processes with the Danube in combination with anthropogenic load on the catchment area of small rivers flowing into Lake Katlabukh, as well as the negative phenomena associated with climate change, create a number of environmental, water and social problems for the lake. The hydrochemical state of the lake water has deteriorated, and water salinity has increased 4-5 times, ie from 800 mg / dm3 to 4.7 g / dm3. Therefore, it is necessary to analyze carefully the hydrological and hydrochemical regime of the lake and the rivers flowing into it, in order to develop both scientific recommendations and operational measures to improve the condition of Lake Katlabukh and optimal conditions for its operation in accordance with the Water Framework Directive 2000/60 / EU (Directive 2000/60/EC, 2000).

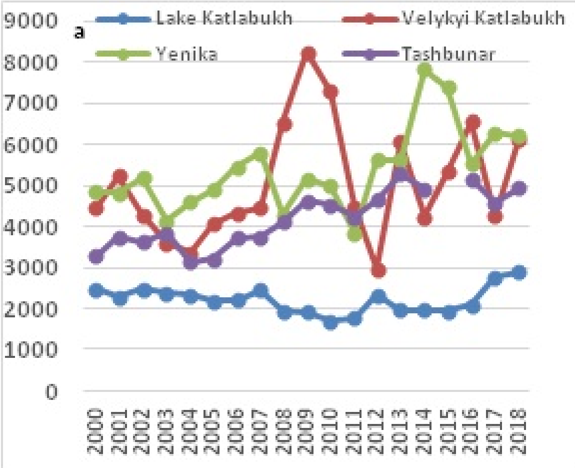
The aim of the work is to analyze the hydrochemical regime and assess the quality of surface waters by hydrochemical parameters in the Danube Lake Katlabukh and its tributaries, using modern calculation methods.

Results

The hydrochemical regime and water quality of Lake Katlabukh are influenced by a number of factors: the volume of runoff of small rivers and its mineralization; the volume of water intake for irrigation and water supply; the amount of precipitation and evaporation from the water surface of lakes; the volume of filling from the Danube and discharge of water into the river (Romanova et al, 2019). Determination of water mineralization was carried out according to the laboratory of the Danube BDWR in such facilities; lake Katlabukh, Velykyi Katlabukh, Yenika, Tashbunar.

The dynamics of the average annual mineralization of water bodies for the period 2000–2018 is shown in Fig.1a. The highest mineralization is observed in the Velykyi Katlabukh and Yenika rivers, which is associated with both natural conditions and anthropogenic pollution.

Lake Katlabukh and the rivers flowing into it are characterized by high water salinity. A significant contribution to such indicators is made, first of all, by sulfate ions, as well as chloride ions, sodium and potassium ions. In order to identify the anthropogenic impact on the hydrochemical regime of the studied objects, studies of pollution with nutrients, organic substances and heavy metals were conducted. To quantify the content of organic matter in the water of Lake Katlabukh and its rivers, the indicators of chemical oxygen consumption (COC) and 5-day biochemical oxygen consumption (BOC5) were used. In surface waters, the values of BOC5 vary from 0.5 to 4.0 mg / dm3 relative to 02 and there are seasonal and daily fluctuations (Fig. 1b). The highest rates of organic pollution are characteristic of the Yenika River and Lake Katlabukh, which is associated with water pollution in the Danube.



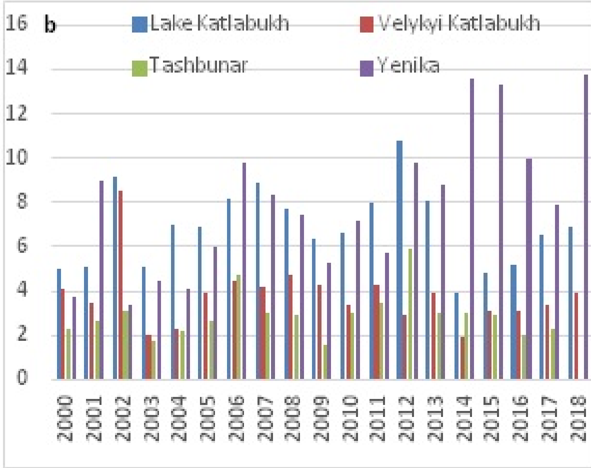


Fig. 1 Average annual values of mineralization (a) and concentration of BOC5 in water of investigated objects (b) for the period 2000–2018, mg / dm^3

The significant pollution by heavy metals (manganese, iron), as well as phenols and, to a lesser extent, petroleum products, is also observed in all studied water bodies. Such a significant degree of pollution, in our opinion, is due primarily to the anthropogenic impact on the catchment area of small rivers. The hydrochemical index of water pollution (HIWP) was also used to assess the water quality of the studied objects (Snizhko, 2001). Estimation of water quality according to IZV was performed on 6 chemical indicators for the lake. Katlabukh, V. Katlabukh river, Yenika river, Tashbunar river: oxygen, phenols, oil products, ammonium nitrogen, nitrite nitrogen and BOC5 based on the data of the Danube BDWR laboratory for 2000–2018. Analysis of the dynamics of the average annual values of HIWP at the observation points for the study period showed that the level of pollutants remains at the same level, fluctuating up or down depending on the anthropogenic impact. The cleanest water in Lake Katlabukh, where the values of HIWP vary from 0.56 (class II) to 1.87 (class III), but there are only five years with water of the third class for the studied period.

Conclusion

The main reason for the unsatisfactory condition of the studied objects is the significant anthropogenic impact on the catchment area of small rivers flowing into Lake Katlabukh, deteriorating the quality of its water resources. One of the main factors in the deterioration of water quality is the lack of water exchange in the lake itself due to a number of negative factors, including geographical location, the impact of climate change, and imperfect management of operational processes.

To improve the condition of surface waters in Lake Katlabukh it is proposed:

• to conduct a detailed analysis of the impact of human activities and natural factors on the water quality of Lake Katlabukh and the rivers flowing into it;

• both for the lake itself and for the territory of its basin to develop a program of specific measures against water pollution by all possible sources of pollution;

• ensure compliance with environmental legislation by all water users, regulate (restrict) or completely prohibit such activities that affect water quality, in particular, fishery water use.

References

Romanova Ye, Shakirzanova Zh, Gopchenko Ye, & Medvedieva Yu. (2019) Water and salt balances of Lake Katlabukh under different operating conditions of the reservoir, *Hydrology, hydrochemistry and hydroecology*, **4** (55), 23–40, (in Ukrainian)

Directive 2000/60/EC of European Parliament and of the Council establishing a framework for the Community action in the field of water policy (EU Water Framework Directive) [Electronic resource] : Act from 23/10/2020. – Access mode: http://eur-lex.europa.eu/resource.html?uri=cellar:5c835afb-2ec6-4577-bdf8-756d3d694eeb.0004.02/DOC_1&format=PDF

Snizhko SI, Assessment and forecasting of natural water quality (2001), Kyiv, Nika-Tsentr, 264 pp. (in Ukrainian)

Formation of the chemical composition of surface waters of the upper Prut River in the Ukrainian Carpathians

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Introduction

The study of the conditions for the formation of the chemical composition of surface waters is an integral part of the main goal of the EU Water Framework Directive – to achieve a good status of water bodies, both surface and underground, within a river basin in a specified time.

The Prut River is one of the largest rivers in the Danube basin; it flows through territories of Ukraine, Romania and Moldova. The Prut River originates on south-eastern slopes of Hoverla Mount, in the mountain massif of the Wooded Carpathians (Chornohora); it flows into the Danube River from the its left bank at a distance of 164 km from the mouth, 0.5 km southeast of the Giurgiulesti village in Moldova. The total river length is 967 km (within Ukraine – 227 km); the catchment area – 27,540 km^2 (within Ukraine – 32 %). The average annual water flow in the river mouth is 110 m^3/s. In hydrological and physical-geographical terms, the river basin is divided into several zones (Khilchevskyi et al., 2019). Among them stands out the upper (mountain) area, which extends from the river source to the village Dora (Ivano-Frankivsk region). The total length of this area is about 43 km and occupies almost 640 km^2 (the length of the Prut River in this area is about 60 km). About 11.5% of the total river runoff is formed in this area (the average long-term water flow of the Prut River in Yaremche is 12.7 m^3/s). Most of the upper reaches of the Prut River are occupied by one of the first (since June 3, 1980) and the largest in Ukraine (504.95 km^2) Carpathian National Nature Park (Carpathian National Nature Park, 2009). In accordance with the order of the Cabinet of Ministers of Ukraine Prut River Headwaters (total area 49.35 km^2) was included in the list of wetlands of international importance.

Methodology

The chemical composition observations of surface waters of the upper Prut River are carried out by specialists of the Carpathian NNP in the control areas, which located above and below the wastewater discharge points: educational and training base “Zaroslyak”; sanatoriums “Hirske Povitria”, “Kremintsi” and the city of Yaremche. In recent years, the network of observations has expanded to 15 points: studies are conducted from time to time on the Chornyi Cheremosh River and its tributaries (Shybenka and Pohorilets), as well as on the Prutets Chemyhivskyi, Meresnyi, Kisnyi and Zhonka streams (Prut's tributaries).

The study of the chemical composition of water was carried out according to the following indicators: major ions (SO_4^{2-}, Cl^-, HCO_3^-, Ca^{2+}, Mg^{2+}, Na^+, K^+); physicochemical parameters (temperature, pH, O_2, BOD_{5days}) and biogenic elements (NH_4^+, NO_2^-, NO_3^-, $N_{gen.}$, $P_{gen.}$). Some of the indicators were determined in the field, for more detailed analysis – in the laboratory of the Carpathian NNP. For this study also was used the results of long-term springs inventory, which conducted in different parts of the Carpathian NNP.

Results

In the highlands (sources of the Prut River and its tributaries), the chemical composition of surface waters is mainly formed under the influence of precipitation. The frequent and heavy rains quickly penetrate rocks poor in soluble minerals, and then appear on the surface in a form of "fresh" (10–30 mg/dm^3), and sometimes “very fresh” (10 mg/dm^3) waters (Kravchinsky et al., 2019), which causes low mineralization of surface waters (20–30 mg/dm^3). The predominant ion here is SO42–, the share of which reaches about 50 % of the sum of all major ions. Together with precipitation, NH4+ and NO3− can enter surface waters in small concentrations (0.2 and 4.7 mg/dm^3, respectively). The pH value in this area varies in significant ranges – from 5.6 (slightly acidic water) in the low water period to 7.4 (slightly alkaline water) in the period of melting snow cover, which can sometimes be observed until July-August. In addition to precipitation, a number of inside water processes take part in the formation of the chemical composition of mountain lakes in this area (for example, Maricheika Lake). Downstream to the village of Vorokhta, water salinity increases to 75–150 mg/dm^3 and is characterized as calcium chloride-hydrocarbonate. The values of physicochemical parameters and nutrients do not change much.

In the area of the Prut River, below the Vorokhta (above and below the wastewater discharges), the water mineralization slightly increases to 140–170 mg/dm^3 and is characterized as sodium-calcium chloride-hydrocarbonate, and in the city of Yaremche – bicarbonate magnesium-calcium. At the same time the concentration in water of all hydrochemical indicators increases. In this area to the closing line (the village of Dora) among the natural factors an important role is played by the underground supply of rivers. The drainage zone of rivers does not exceed 80 m, so the vast majority of groundwater is "very fresh" and "normally fresh" (30–500 mg/dm^3). Sometimes there are specific groundwater with high mineralization (Kravchynskyi et al., 2019), which do not have a significant effect on the transformation of the chemical composition of surface waters. The tourist-recreational complex has the greatest influence in this area. The main pollutants of the Prut river basin ecosystem here are discharges of untreated wastewater and diffuse sources of pollution. Non-canalized terrain also causes the emission of organic and biogenic compounds into the river basin (Korchemlyuk et al., 2019). In this territory the surface waters constantly fixed (though in small concentrations) maintenance of ammonium nitrogen (0.1–0.5 mg/dm^3), nitrates (1.8–12.5 mg/dm^3), nitrites (0.02–0.07 mg/dm^3) and phosphates (0.02–0.08 mg/dm^3). During rainy floods, the concentration of the above indicators decreases. However, there is an increase in the pH value (8.5–8.9, sometimes 9.0–9.2) and entering the river network with surface runoff of petroleum products and other specific pollutants. It is characteristic that in the village. Dora in the Prut River (closing line) often shows a decrease in the concentration of some chemical indicators, in particular, the amount of ions. This is probably due to the inflow of cleaner and less mineralized (55–140 mg/dm^3) waters of the Prutets Chemyhivskyi, Kisnyi, Meresnyi and Zhonka rivers into the main waterway in the interval between the village of Mykulychyn to the city of Yaremche.

In the study, special attention was paid to the oxygen regime. The mountainous nature of the river causes high turbulence of the flow along its entire length within the Carpathian NNP, there are often river rapids, there are waterfalls. This helps to saturate the water with oxygen. The content of dissolved oxygen in water averages 8.0–8.5 mg/dm^3 per year, and the oxygen saturation of water is over 80 %. Below the discharge sites of domestic wastewater, a decrease in the concentration of O_2 in water (6.7–7.7 mg/dm^3) is often observed. During rain floods, together with the surface-slope runoff, a significant amount of clay material enters the river network, in which microelements are accumulated, in particular, the increased content of iron ions. Therefore, part of the oxygen dissolved in water is spent on the oxidation of metals and some other substances, and the O_2 itself may for a short period decreased to the level of 7.0–7.8 mg/dm^3.

Conclusion

According to the conditions of formation of the chemical composition of surface waters, the research area can be divided into two sections: 1– from the source to the urban-type settlement of Vorokhta (total river length about 20 km), where the mountainous nature of the river prevails and there is no (conditionally) anthropogenic impact; 2 – from village of Vorokhta to the village of Dora, where a well-developed tourist and recreational complex is periodically discharged domestic wastewater from sanatoriums and recreation facilities. In 2020, an improvement in the hydro-ecological situation in the upper reaches of the Prut River was revealed, which is probably due to the epidemiological situation in the country and the decrease in tourist flow to the region. In recent years, there has been an impact of global climate change on water resources of the study area: changes in precipitation, reduced river runoff, increased water temperatures, deterioration of the oxygen regime of rivers, intensification of intra-water processes, etc.

References

Carpathian National Nature Park (2009) Ed. Prykhodko MM, Kiselyuk OI, Yavorsky AI. Ivano-Frankivsk, 672 pp. (In Ukrainian).

Khilchevskyi VK, Grebin VV, Sherstyuk NP (2019) Modern Hydrographic and Water management zoning of Ukraine's territory in 2016 - implementation of the WFD-2000/60/EC, Electronic book with full papers from XXVIII Conference of Danubian countries on the hydrological forecasting and hydrological bases of water management. Kyiv, 209-223. https://uhmi.org.ua/conf/danube_conference_2019/papers_abstracts/Electronic_Book_Danube_Conference_2019.pdf

Korchemlyuk M, Arkhipova L, Kravchynskyi RL, Mykhailyuk JD (2019) Anthropogenic influence from point and diffuse sources of pollution in the Upper Prut River basin, *Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu*, **1**, 125–131.

Kravchynskyi RL, Khilchevskyi VK, Korchemlyuk MV, Stefurak OM (2019) Monitoring of the springs of the Carpathian National Natural Park, Ivano-Frankivsk, 124 pp. (In Ukrainian).

Issues of Operational Hydrology in Ukraine in the Context of WMO Strategy and Organizational Arrangements for Hydrology and Water Resources

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Introduction

Over the past few years, the World Meteorological Organization (WMO) has organized a number of landmark events that addressed the development of activities in the field of hydrology and water resources at national, regional and international levels: the WMO Global Conference on Prosperity Through Hydrological Services, 2018; the 70th Session of WMO Executive Council, 2018; the Extraordinary Session of WMO Commission for Hydrology, 2019; the 18th Session of World Meteorological Congress (18th WMC), 2019; the First Forum of Hydrological Advisers for WMO Regional Association -VI (Europe), 2020; the WMO Data Conference, 2020. The decisions taken at these events largely relate to the hydrological activity in Ukraine both in a broad sense (practice, science and education ones) and in its specific area, namely, operational hydrology. *The purpose* of this publication is to consider the current state and directions for the development of operational hydrology in Ukraine in the context of WMO initiatives.

Methodology

The paper is prepared on a basis of analysis of needs of operational hydrology in Ukraine and WMO initiatives, in which directions of development in the field of hydrology and water resources are considered.

Results

New WMO initiatives

Taking into account the growing demands of society for a study and protection of water resources as well as present achievements in a development of scientific and applied hydrology, WMO at its 18th WMC adopted the new definition of the term "Operational Hydrology" as "...the real-time and regular measurement, collection, processing, archiving and distribution of hydrological, hydrometeorological and cryospheric data, and the generation of analyses, models, forecasts and warnings which inform water resources management and support water-related decisions, across a spectrum of temporal and spatial scales. Operational hydrology requires capacity building and scientific and technical advancement and innovation in the areas of observation, data standards and services, modeling, prediction, hydro-informatics and decision support, communications, training, and outreach". It was decided by the 18th WMC to prepare the Plan of Actions " ...to strengthen operational National Hydrological Services and the capabilities of national service providers that will support Member states' efforts to fulfil the following Long-term Ambitions: (a) no one is surprised by a flood; (b) everyone is prepared for drought; (c) hydro-climate and meteorological data support the food security agenda; (d) high-quality data supports science; (e) science provides a sound basis for operational hydrology; (f) we have a thorough knowledge of the water resources of our world; (g) sustainable development is supported by informationcovering the full hydrological cycle; (h) water quality is known". The following ongoing activities and systems have been identified by WMO to achieve Long-term Ambitions: 1) quality Management Framework - Hydrology and its further implementation with the aim of promoting a stronger culture of compliance and quality assurance; 2) assessment of performance of flow measurement instruments and techniques: the development of software to assist Hydrological Services to assess the uncertainty of discharge measuring; 3) the HydroHub: implementation of HYCOS components according to countries priorities under new WHYCOS framework; 4) hydrological data operational and management: the implementation of WMO WHYCOS Phase II, in accordance with its Implementation Plan endorsed by WMO EC-71; 5) the WMO Flood Forecasting Initiatives and hydrological contributions to disasters risk management; 6) WMO Global Hydrological Status and Outlook System which is aimed to produce regular analyses of current national hydrological conditions complimented by forward looking assessment of how the water situation may change over sub-seasonal and seasonal time scales, and taking into consideration the need to link this initiative closely with other relater WMO activities; 7) the WMO Strategy for Capacity Development and Water Resources Management; 8) the World Water Data Initiative which is aimed to promote national strategies to improve water information.

Present status of operational hydrology in Ukraine

According to the Ukrainian legislation issues of operational hydrology belong to a competence of the State Hydrometeorological Service (SHMS), which is under a management of the State Emergency Service of Ukraine. The hydrological and related meteorological information, forecasts and warnings of SHMS are widely used by the different water -depended sectors of the national economy. It should be say that combining meteorological and hydrological activities into one state body facilitates an interaction of meteorologists and hydrologists, which has a positive impact on the quality of hydrometeorological services provided to end - users. In addition to the Hydrometeorological Service, the measurement of quantitative and qualitative variables of water resources is performed by: the State Agency of Water Resources (on water reclamation systems); higher educational institutions (in a process of training specialists – hydrologists). It should be note that these institutions use a methodology of measuring hydrological variables used by the Hydrometeorological Service. Unfortunately, there are a number of problematic issues (logistical, technological and financial ones) in activities of the Hydrometeorological Service, some of which are systemic and long-lasting. These issues are considered in this article in details. Logistical issues complicate the management of the Hydrometeorological Service, especially in cases that require urgent solutions. Technological and financial ones stand in a way of upgrading all segments of a chain of hydrometeorological activity - from primary observations up to providing end-users with products and services. The Hydrometeorological Service of Ukraine takes measures to overcome existing difficulties in its activity. The State Target Program of Material and Technical Development of the National Hydrometeorological Service for the Period 2022–2024 was developed by the State Emergency Service and the State Hydrometeorological Service, and it should be approved by the Government of the country. The measures to be taken within the Program to improve hydrological activities are considered in the article. In particular, the Program provides for the strengthening of international cooperation at the global and regional levels.

Participation in WMO initiatives

The Hydrometeorological Service is interested to participate in all WMO hydrological initiatives mentioned above, as, on the one hand, it hopes to gain a new knowledge and a good experience from international partners, and, on the other hand, it will be able to present achievements of Ukrainian scientists in hydrological researches and equipment manufacturers in development and production of hydrological technologies. Some of these researches and technologies have gained recognition outside Ukraine. The publication addresses in detail the following issues: a) in which areas of WMO hydrological activities Ukraine plans to participate; b) what knowledge and practical experience the Ukrainian scientific and practical hydrology can gain from participation in these WMO initiatives; c) what scientific and technical achievements the Ukrainian scientists and manufacturers can offer to international partners; d) what organizational measures should be taken by the Hydrometeorological Service of Ukraine in order to benefit most from participation in WMO initiatives.

Conclusions

Participation in WMO strategic initiatives in the field of hydrology and water resources will contribute to the development of operational hydrology in Ukraine,that will have a positive impact on the water sector development in the country as a whole.

Evaluation of regional and global precipitation reanalysis products for rainfall-runoff modelling in selected Slovenian catchments

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Introduction

The determination of design discharges for ungauged catchments is a continuing challenge especially for small catchments. The reliability of hydrological modelling to overcome this obstacle is, among others, significantly dependent on the quality of input precipitation time series with a sufficient temporal and spatial resolution. Often, observed rainfall time series are either too short or the network density is too low to meet the requirements of the intended application.

Precipitation reanalysis products (PRP) are a valuable source of rainfall data to be used in hydrological modelling as they offer a spatially homogenous and temporally continuous source of meteorological information (Sun et al., 2018). With the update and improvement of numerical weather prediction models along with increasing spatial resolution the popularity of the PRP is increasing, since they represent a promising data set for local hydrological analysis.

PRP differ regarding their spatial and temporal resolution, their available period, their sources and the way they were determined. Since observations are a key input variable, the PRP differ especially in unobserved regions from each other and have to be carefully validated for each study area.

Methodology

In this study the high-resolution PRP in Table 1 are validated for Slovenia. In a first step, PRP are compared to gauge-based rainfall observations covering Slovenia. The comparison includes event-based and continuous time series characteristics as well as rainfall extreme values (Figure 1). A spatial validation includes a spatial interpretation of the gauge-based validation results for single PRP as well as an analysis of the spatial consistence of the PRP (Müller and Haberlandt, 2015, Müller-Thomy et al., 2018).

After the validation of rainfall characteristics, the most promising PRP will be validated by hydrological modelling of selected Slovenian catchments under the usage of the lumped rainfall-runoff model GR4H (Sezen et al., 2019). The evaluation of the resulting hydrographs will offer additional insights into the suitability of these datasets for hydrological modelling in Slovenia as they represent a cumulative validation of the PRP in space and time, including the high non-linearity of the rainfall-runoff transformation process. The hydrological model will be calibrated by split-sampling and evaluation of the KGE over the whole time series separately for each PRP.

Table 1 Reanalysis data sets for evaluation and subsequent use as input time series in hydrological modeling of selected Slovenian catchments.

Reanalysis Product	Spatial Resolution	Temporal Resolution	Time span	Institution	Publication
ERA5-Land	~9 km	1 hour	01/1981-ongoing	ECMWF	Muñoz Sabater (2019)
REA6	~6 km	1 hour	01/1995-06/2019	DWD/COSMO	Bollmeyer et al. (2015)
CFSR	~38 km	1 hour	01/1979-12/2010	NCEP	Saha et al. (2010)
CFSv2	~22 km	1 hour	01/2011-ongoing	NCEP	Saha et al. (2011)

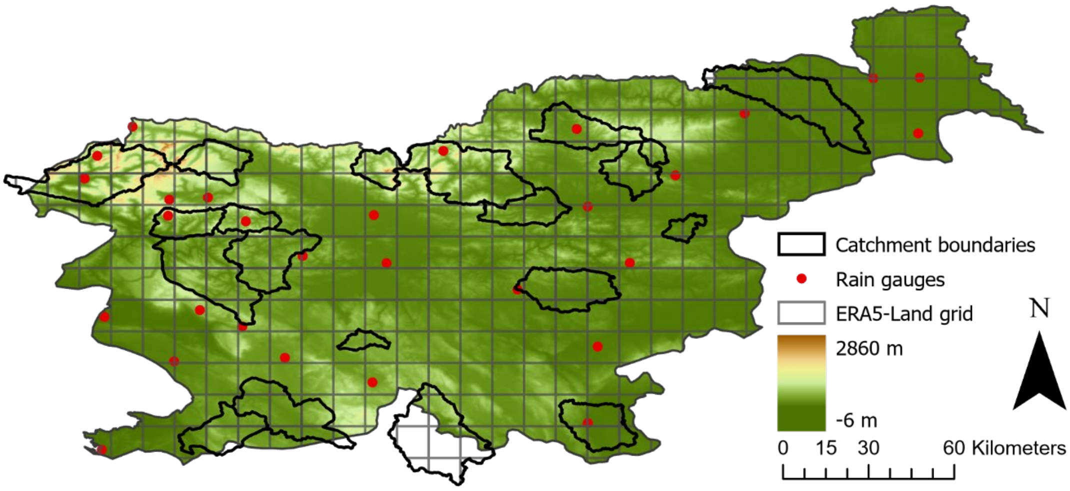

Fig. 1 Location of rain gauges and catchments used for rainfall-runoff modelling in Slovenia. The ERA5 raster is added exemplarily to provide an impression of the dimensions and relations of the data sets used.

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References

Bollmeyer, C., Keller, J. D., Ohlwein, C., Wahl, S., Crewell, S. et al. (2015): Towards a high-resolution regionalreanalysis for the European CORDEX domain.Q. J. R. *Meteorol. Soc*. **141**, 1–15. 2486. doi:10.1002/qj.2486

Müller, H., Haberlandt, U. (2015): Temporal rainfall disaggregation with a cascade model: from single-station disaggregation to spatial rainfall, *Journal of Hydrologic Engineering,* **20** (11), 04015026

Müller-Thomy, H., Wallner, M., Förster, K: (2018): Rainfall disaggregation for hydrological modelling: Is there a need for spatial consistence?, *Hydrology and Earth System Science*, **22**, 5259–5280

Muñoz Sabater, J., (2019): ERA5-Land hourly data from 1981 to present. Copernicus Climate Change Service (C3S) Climate Data Store (CDS). (Accessed on 01-05-2021), 10.24381/cds.e2161bac

Saha, S., et al. 2010. *NCEP Climate Forecast System Reanalysis (CFSR) Selected Hourly Time-Series Products, January 1979 to December 2010*. Research Data Archive at the National Center for Atmospheric Research, Computational and Information Systems Laboratory. https://doi.org/10.5065/D6513W89. Accessed† 01-05-2021.

Saha, S., et al. 2011, updated monthly. NCEP Climate Forecast System Version 2 (CFSv2) Selected Hourly Time-Series Products. Research Data Archive at the National Center for Atmospheric Research, Computational and Information Systems Laboratory. https://doi.org/10.5065/D6N877VB. Accessed† 01-05-2021.

Sezen, C., Bezak, N., Bai, Y., Šraj, M. (2019): Hydrological modelling of karst catchment using lumped conceptual and data mining models, Journal of Hydrology, doi: 10.1016/j.jhydrol.2019.06.036.

Sun, Q., Miao, C., Duan, Q., Ashouri, H., Sorooshian, S., & Hsu, K.-L. (2018). A review of global precipitation data sets:

Data sources, estimation, and intercomparisons. *Reviews of Geophysics*, **56**, 79–107. https://doi.org/10.1002/2017RG000574

Flood Discharges Analysis at River Confluences – PROIL model

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Abstract

The theoretical background for determining the level of coincidence of flood discharges at river confluences is outlined in the paper. Considering the case of a river reach bounded by two input cross-sections (of the recipient and a tributary) and one output cross-section (of the recipient), with no major inflow from the intermediate basin, combinations of maximum annual discharges and corresponding discharges are defined. Mathematical model is based on two-dimensional probability distribution (PROIL model). The results of the proposed model are shown for the reach of the Danube River from the gauging station in Vienna to the gauging station in Bratislava, including the lower course of the Morava River.

Introduction

When structural flood protection measures are assessed, it is common to determine the design river discharge based on the probability that a flood will exceed a pre-defined flood wave peak, which is equivalent to the return period of the flood. The calculation procedure involves a statistical analysis of flood discharges at the nearest gauging station. Practice has shown that such an approach is justifiable when there are no confluences along the considered river reach. However, hydrologic gauging stations (GS) are located away from confluence zones, so it is extremely important to determine the level of flood wave coincidence on the two rivers, to select spatially dependent design event and to define the design flood discharge based on the two-dimensional probability distribution.

This paper presents a model PROIL for the coincidence of two random variables determination, maximum and corresponding discharges at the recipient and tributary and the practical application of the proposed model in defining: design water level at river confluence and statistical assessment of historical flood.

Methodology

PROIL model

To determine the design water levels within the zone of mutual influence of the recipient and the tributary, the probability of simultaneous occurrence of flood waves on the two rivers needs to be defined. These are random events on the recipient and the tributary (*X* and *Y*).

When two-dimensional random variables are normally distributed, density function $f(x,y)$ (lines of same probabilities of occurrence of random variables *X* and *Y*) can be expressed as Prohaska et al. (1999) defined:

$$f(x,y)=\frac{1}{2\pi\cdot\sigma_x\cdot\sigma_y\cdot\sqrt{1-\rho^2}}\cdot e^{-\frac{1}{2\cdot(1-\rho^2)}\cdot\left[\frac{(x-\mu_x)^2}{\sigma_x^2}-\frac{2\rho\cdot(x-\mu_x)\cdot(y-\mu_y)}{\sigma_x\cdot\sigma_y}+\frac{(y-\mu_y)^2}{\sigma_y^2}\right]}, \quad (1)$$

where:

x, y – simultaneous occurrence of random variables *X* and *Y*, respectively; μ_x, μ_y – mathematical expectations for *X* and *Y*; σ_x, σ_y – standard deviations of *X* and *Y*; ρ – correlation coefficient of *X* and *Y*.

To obtain the distribution density, $f(x,y)$ the first step is to determine marginal probabilities $f(x,\bullet)$, $f(\bullet,y)$ and then their cumulative probabilities $F(x,\bullet)$, $F(\bullet,y)$.

The next step is to determine the probability of exceedance $\Phi(x,y)$ in bivariate probability space (Prohaska et al., 1999; Prohaska and Ilić, 2010):

$$\Phi(x,y)=\int_{t=x}^{t=+\infty}\int_{z=y}^{z=+\infty}f(t,z)dtdz=P[X>x\cap Y>y]=1-P[X<x\cup Y<y]=$$
$$=1-F(x,\bullet)-F(\bullet,y)+F(x,y) \qquad (2)$$

The corresponding daily and maximum annual discharge series of the Danube (at GS Vienna and GS Bratislava) and the Morava (at GS Moravsky Jan) were obtained from the database of the UNESCO project No.9 "Flood Regime of Rivers in the Danube River basin".

Results

Flood Discharges of Characteristic Probabilities at the River Confluences

In the specific case, the coincidence of flood discharges of the Danube and the Morava was estimated for the following combinations of variables: (1) Maximum annual discharge at GS Vienna – corresponding discharge at GS Bratislava, (2) Corresponding discharge at GS Vienna – maximum annual discharge at GS Bratislava, (3) Maximum annual discharge at GS Vienna – corresponding discharge at GS Moravsky Jan, (4) Corresponding discharge at GS Vienna – maximum annual discharge at GS Moravsky Jan, (5) Maximum annual discharge at GS Bratislava – corresponding discharge at GS Moravsky Jan, (6) Corresponding discharge at GS Bratislava – maximum annual discharge at GS Moravsky Jan.

The theoretical discharges along the Danube from GS Vienna to GS Bratislava, and the Morava from GS Moravsky Jan to the confluence with the Danube, are shown in Table 1.

Table 1. Theoretical discharges for different coincidence probabilities of the Danube and the Morava

p%	Danube upstream from confluence			Danube downstream from confluence			Morava upstream from confluence		
	$Q_{\max}^{Vienna}$	Q_{cor1}^{Brat}	Q_{cor1}^{MJ}	$Q_{\max}^{Brat}$	Q_{cor2}^{Vienna}	Q_{cor1}^{MJ}	$Q_{\max}^{MJ}$	Q_{cor2}^{Brat}	Q_{cor1}^{Vienna}
0.1	12922	6000	31	13760	6500	22	2170	2500	2100
1.0	10309	5800	30	10906	6100	19	1541	1800	1700
5.0	8463	5300	28	8890	5100	16	1131	1500	1250

Assessment of Statistical Significance of Historic Floods

The return periods of the largest floods on the Danube in previous centuries occurred in September in 1899 and in July 1954 are analyzed according to the results of the coincidence of flood discharges.

The flood in 1899 can be assessed with return period of 300 years and in 1954 with return period of 200 years.

Conclusion

The practical significance of the coincidence analysis is that flood protection might be designed according to discharges that require a lower level of flood protection within the zone of mutual interaction of the recipient and a tributary, relative to the conventional one-dimensional procedure, while ensuring the same level of protection from a flood risk perspective. The proposed PROIL model provides quantitative design indicators of optimal combinations of the considered random variables, from the viewpoints of structural integrity and economics.

These results have been included into the long-term forecast of the runoff regime in the Danube River basin.

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References

Prohaska, S., Isailović, D., Srna, P., Marčetić, I., 1999. The Danube and its Basin – A Hydrological Monograph Follow-up volume IV, Coincidence of Flood Flow of the Danube River and its Tributaries, Regional Co-operation of the Danube Countries in the Frame of the International Hydrological Programme of UNESCO, pp 1–187, Water Research Institute Bratislava, Slovakia.

Prohaska, S., Ilic, A., 2010. Coincidence of Flood Flow of the Danube River and Its Tributaries, (In: Mitja Brilly (Ed.): Hydrological Processes of the Danube River Basin - Perspectives from the Danubian Countries), Publisher: Springer, ISBN 978-90-481-3422-9, Book Chapter 6, p. 175–226. DOI: 10.1007/978-90-481-3423-6_6

Groundwater response to extreme flows in the Danube River

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Introduction

The Danube River is the main hydrological factor which controls the formation and hydrodynamics of groundwater along its course in Bratislava and downstream. There is continuous dynamic interaction between the groundwater and the Danube River. The water level in the river is located above the groundwater table throughout the whole year, and it permanently replenishes the groundwater reservoir. After construction of the Gabčíkovo hydropower plant, the effect of back water of the reservoir is extended upstream up to Bratislava, i.e., the water level in the Danube is increased so as the groundwater at the vicinity of the river. The process of this interaction is mostly very complex to solve. The seepage between the river and the adjacent aquifer system occurs along their entire intersection and it depends on the river stage, hydraulic head in the groundwater system and the riverbed conductance (Winter et al., 1998).
The presented paper deals with the numerical modelling of groundwater response to the extreme hydrological situations in the Danube River. A numerical groundwater modelling is carried out using MODFLOW (Michael et al., 1998) and GMS simulation packages for available hydrological, geological and hydro-geological parameters to study how the groundwater responded to a flood events in the Danube River that occurred in May−June 2010 and 2013 (0.) To calibrate the model parameters for both steady state and transient flow including hydraulic conductivity and river conductance, observed groundwater head in 17 boreholes of Slovak Hydro-meteorological Institute (SHMI) were used. The results of the model are in a good agreement with the observed data and therefore, the model can be used for studying and analyzing the changes and movements of the groundwater level in the aquifer in response to the flow conditions in the Danube River.

Methodology

The MODFLOW and GMS model which are used to solve finite-difference equations of groundwater flow, require many spatial and non-spatial data inputs. Therefore, input data collection, creation and analysis will be an important component in this study. Most of the spatial data will be created from terrain analysis of the Digital Elevation Model (DEM) which will be processed using different approaches. Then the stream networks and hillslopes are created from terrain analysis of the processed DEM. Archive data about groundwater hydrology for the period of 2002 to 2016 is obtained from the Slovak Hydro-Meteorological Institute (SHMI). Based on request, the SHMI institute also provided precipitation data from Bratislava-airport and Bratislava-Koliba station. Specifically, weekly precipitation data is obtained for the period of 2002 to 2016 to estimate effective recharge rate. The values of horizontal hydraulic conductivities of the aquifer were collected from archive data of State Geological Institute of Dionýz Štúr (SGIDŠ).
The boundary of the model is created by considering surface water divides and physical topography of the study area. The processed input data were used to create a conceptual model which is associated to calculation grids. Horizontally, finite-difference computation networks of 236 columns by 374 rows were discretized. Four model layers were created to divide the aquifer in the vertical direction. The assigned boundary conditions for the steady sate simulation include: general head in the Danube River on the western side, artificial boundary condition of general head on the eastern side, general head in Little the Danube on the southern side, and flux to the boundary on the northern side of the boundary.

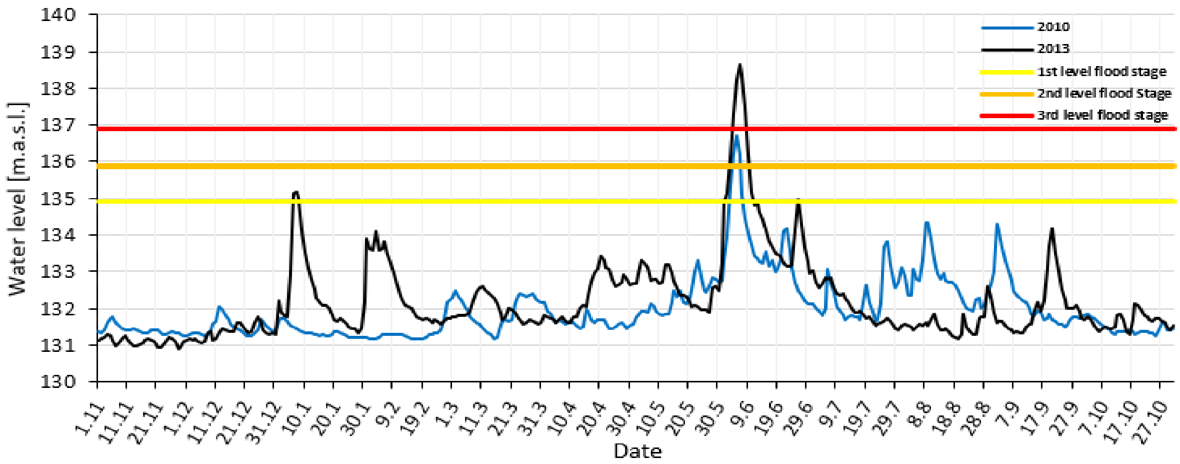

Fig. 1 Water level in the Danube River at Bratislava gauging station for the hydrologic year 2010 and 2013 and proposed flood warning levels by SHMI

The transient simulations were carried out by considering the flood event in the Danube River at Bratislava gauging station for the period of 2010 and 2013. Both flood events were occurred in the same month (May−June), however, the magnitudes were different. In 2010, the water level started to rise around the end of May and reached peak level of 136.7 meter above sea level (m.a.s.l.) on June 5. The flood event was recognized as 2nd level flood stage. In 2013, the water level also started to rise at the end of May and reached peak level of 138.65 m.a.s.l. with culminated discharge of 10 641 m^3.s^{-1} on June 6 (Pekárová et al., 2013). It was recognized as a 3rd level flood stage.

Results

Transient simulation was carried out based on hydrological situation in the Danube River. The increase in water level in the Danube River caused a significant change in groundwater level in the narrow adjacent area. However, the change in water level was insignificant in the areas far from the banks of the river. This indicates that there will be parallel flow of groundwater along the river. The result also showed that the flow of the groundwater is towards the southwest of Slovakia, where Rye Island is located. The rise in water table and groundwater flow towards this area could have positive and negative impacts. As a positive impact, groundwater around Rye Island could be recharged. As a negative impact, there might be movement of toxic contaminants from bombarded Appolo refinery, which is in Bratislava at the banks of the Danube River, along groundwater flow during peak hydrological situations.

Conclusion

3-D groundwater flow was modelled to investigate the interaction between aquifer and river. The main analysis was focused on a transient flow for specific flood events that occurred in two different periods (i.e. 2010 and 2013). Even though most of the simulated transient head matched the observed head in boreholes of SHMI during the flood events, certain lag time differences were observed in some of them (i.e. short lag time between observed and simulated peak heads). The obtained results could be used as a relevant information for water resources planning and management. It could also be used as a base for further study on contaminant movement from Bratislava towards Rye Island along the Danube River.

Acknowledgements

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References

McDonald MG, Harbaugh AW (1998) A Modular Three-Dimensional Finite-Difference Ground-Water Flow Model, Dallas,539 pp

Pekárová P, Halmová D, Bačová M, Miklánek P, Pekár J, Škoda, P (2013) Historic flood marks and flood frequency analysis of the the Danube River at Bratislava, Slovakia, *Journal of Hydrology and Hydromechanics,* **61**, 326–333

Winter TC, Harvey JW, Franke OL, Alley WM, (1998) Ground Water and Surface Water: A Single Resource, Denver 98 pp

Hydrological analysis of the Danube regime on the section through the Republic of Croatia and the Republic of Serbia

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Introduction

The Central Danube Region is an impressive and unique geographical entity in Europe. It is bounded by Carpathian sand, a part of the Balkan Mountain, in the north and east, near the Alps in the west, and the Dinarides in the south. This closed circle of mountains includes the "Pannonian Basin System", which consists of the southeastern and Slovak lands, the Lesser and Great Hungarian Lowlands, the Transylvanian Basin, the Slavonian Middle Range, the Sava Basin, and part of the Great Morava Basin (Schiller et al., 2010). With its central part, the Danube river runs through Croatia and Serbia and represents the border between these countries. In this part of the Danube basin, the Danube flows along the Kopački rit swamp, while the two large rivers, the Drava and the Sava flow into it, which significantly affects the very regime of the Danube. The surface of the Danube river basin in Croatia is 35,101 km^2, which represents 62% of the Croatian land territory. (Croatian River Basin Management, CRBM 2016–2021). Changes in river flow regimes due to changes in climatic elements primarily in Europe refer to the way rivers are supplied, ie the type of their recharge. (Čanjevac, 2012) This paper contains a hydrological analysis of the Danube regime using measured flow data at four gauging stations; Batina in the Republic of Croatia, and the stations Bezdan, Bogojevo, and Smederevo in the Republic of Serbia for the period 1992–2018.

Material and methods

The paper analyzes databases on measured flows at Batina, Bezdan, Bogojevo, and Smederevo. Correlation analysis was performed between the Batina station and the closest one to it in the Republic of Serbia - Bezdan station due to the insufficient length of the series of available data for the Batina station. Given that the analysis determined an extremely strong correlation (correlation coefficient is 0.998), flow analysis was performed for the Bezdan station, the results of which can be considered representative for the Batina station as well the Republic of Croatia. Based on the data on mean daily flows, the minimum, mean and maximum annual flows were obtained. Statistical processing of the data constructed flow duration curves and frequency histograms for the average daily flows of the Danube River for the Bezdan (Batina), Bogojevo, and Smederevo stations, and additionally singled out characteristic curves for the dry, normal, and wet years recorded for the given series 1992–2018. The classification of the flow regime is defined according to Parde's modulus coefficients. The flows shown in modular coefficients are suitable for comparing individual hydrological features at different hydrological stations. The hydrological analysis of the seasons was performed, ie the flow tendencies for the hot and cold seasons for the observed period were shown.

Results

By processing the database on mean daily flows, the following results were obtained: for the station Bezdan (Batina) the lowest mean daily flow of 742 m^3/s was recorded in October 1992, and the largest of 8380 m^3/s in June 2013. A slight upward trend is visible for minimum and maximum annual flows, while for the medium trend the increase is very slight to none. For the Bogojevo station, the lowest mean daily flow of 926 m^3/s was recorded in September 2003, and the largest of 8700 m^3/s in June 2013. There is a considerable upward trend in the minimum and medium annual flows, while for maximum annual flows the upward trend is slightly negative.
For the Smederevo station, the lowest mean daily flow of 1400 m^3/s was recorded in September 2003. and the largest of 14800 m^3/s in April 2006. At minimum annual flows for the aforementioned station are showing a strong positive trend. For medium annual flows it is very visible a slight upward trend and for maximum annual flows a slight decline. Correlation analysis confirms strong dependence between stations Batina and Bezdan, Bezdan and Bogojevo, while the results of correlation analysis for Bogojevo and Smederevo stations showed that there is almost no gap between them no correlation. The analysis of the mean monthly flows expressed in Parde's modular coefficients shows that the Danube at the stations Batina (Bezdan) and Bogojevo has an alpine snow regime and

at the station Smederevo a combined complex regime. For the Bogojevo station, a more significant positive trend of average monthly flows for the warm and cold seasons during the observed period is noticed. The lowest average monthly flow of the warm season of 1701 m^3/s was recorded in 2003, and the cold 2014 m^3/s was recorded in 1997. The average monthly warm season is 3016 m^3/s and cold 2471 m^3/s. The highest average monthly of the warm season was 4250 m^3/s recorded in 2006, and the cold season 3137 m^3/s recorded in 2002. Finally, for the Smederevo station, the results show a slight increase in mean monthly flows for both seasons with the proviso that it should be noted that for the observed series from 1992 to 2018 one is missing data period from 1997 to 2000 so the results for this station should be taken with a smaller dose of reliability. The lowest average monthly flow of the warm season of 2893 m^3/s was recorded in 2003, and the cold average of 3898 m^3/s was recorded in 2012. The mean monthly average of the warm season is 5103 m^3/s, and of the cold 5041 m^3/s. The highest average monthly of the warm season was 7368 m^3/s recorded in 2006, and in the cold season 7018 m^3/s recorded in 2010. (Djedovic, 2020)

Conclusion

On the section of flow through Croatia and Serbia, the Danube River has two flow regimes: the alpine rain-snow regime (stations Batina, Bezdan, and Bogojevo) and the regime of combined-complex nature at the station Smederevo. The change in the flow regime of the Danube is a consequence of the confluence of the Sava River with the Danube, which has a Pannonian rain-snow regime. The analysis of hydrological seasons and trends of increase/decrease of average monthly flows between the mentioned stations confirms the heterogeneity of the catchment area and different runoff regimes between the stations due to the significant size and complexity of the basin and runoff on it.

References

Croatian River Basin Management, 2016–2021
http://www.voda.hr/sites/default/files/plan_upravljanja_vodnim_podrucjima_2016._-_2021.pdf (accessed on February 15, 2018, March10, 2018, April 3, 2018)

Čanjevac, I (2012): Changes in Discharge Regimes of Rivers in the Croatian Partof the Danube River Basin, *HRVATSKI GEOGRAFSKI GLASNIK* **74**/1, 61–74

Djedović, I (2020): Analysis of the Danube river runoff regime through the Republic of Croatia and the Republic of Serbia, J.J.Strossmayer University of Osijek Faculty of Civil Engineering and Architecture Osijek, Croatia, graduate thesis

Schiller H., Miklós D., Sass J. (2010) : The Danube River and its Basin Physical Characteristics, Water Regime and Water Balance, Hydrological Process of Danube River, pages 25–77

Relation of influencing variables and general weather conditions on response of rainfall partitioning by birch and pine trees

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Introduction

The hydrological cycle is influenced by multiple natural and artificial elements. As part of vegetation, the trees significantly influence the cycle through the process of rainfall partitioning. The components of rainfall partitioning are rainfall interception (I), describing the amount of rainfall, captured by the canopy and evaporating to the atmosphere, throughfall (TF), reaching the ground by dripping from the branches or falling through the openings, and stemflow (SF), precipitation trickling down the stem. How the precipitation is distributed after its interaction with a tree depends on multiple interconnected parameters (Staelens et al., 2008; Šraj et al., 2008; Zabret et al., 2018). Usually, they are divided on meteorological properties of an event (e.g. rainfall amount, intensity, wind speed) (Van Stan, 2014) and vegetation variables of a tree (e.g. tree height, canopy characteristics, bark absorption) (Zabret, 2013). As the variables are interdependent, it is hard to understand these processes. The complex interactions were addressed in multiple previous studies, taking into account different combinations of variables and presenting different viewpoints (Staelens et al., 2008; Šraj et al., 2008; Van Stan et al., 2014; Zabret et al., 2018; Zabret and Šraj, 2019). Therefore, the objective of this study is to contribute to the understanding of complicated processes with an analysis of a long term data set with advanced statistical model, including different tree species (deciduous and coniferous) and phenophases.

Methodology

The data on rainfall events and interception were collected on a study plot (600 m^2), located in a small urban park in the city of Ljubljana, Slovenia (46.04^0 N, 14.49^0 E), characterized by continental climate. It consists of a clearing and of two separate groups of trees, the birch trees (*Betula pendula* Roth.) and the pine trees (*Pinus nigra* Arnold). On the study plot the measurements are ongoing since January 2014. Rainfall was measured on the clearing with a tipping-bucket rain gauge (Onset RG2-M, 0.2 mm/tip) and with a disdrometer on the rooftop of a nearby building (OTT Parsivel). Throughfall (TF) was measured under each group of trees with ten roving wedge gauges (78.5 cm^2) and with two steel through gauges (0.75 m^2), one connected to manually-read polyethylene containers and the other one equipped with tipping bucket flow gauge (Unidata 6506G, Onset HOBO Event, 50 ml/tip). Stemflow (SF) was captured by halved rubber hose, spirally wrapped around the stem of one tree of each group and connected to a tipping bucket (Onset RG2-M, 0.2 mm/tip). Data on additional meteorological variables were obtained from the nearest meteorological station Ljubljana-Bežigrad.

The statistical analyses were performed in R software (R core team, 2020), with the boosted regression tree analysis (BRT) and with correlation matrices. The variables, taken into account, were rainfall amount (Ra), duration (Rd) and intensity (Ri), median volume diameter of raindrops (MVD), number of raindrops (Nr), air humidity (H) and temperature (T), wind speed (Ws) and duration of dry period between the events (DrP).

Results

The analyzed data were collected in the period from 1 January 2014 to 30 June 2017, when 415 rainfall events were considered. The selected rainfall events delivered 4,111.6 mm of rainfall in total. The events were on average 8.5 hours long and the rainfall intensity per event was on average equal to 2.5 mm/h. Under the birch trees the observed TF was on average equal to 54% (± 44%) per event, SF was observed during 188 events and was on average equal to 1.2% (± 2.4%). Therefore, rainfall interception by birch tree was on average equal to 31% in leafless and 51% in leafed period (Fig. 1). Under the pine trees, TF on average accounted for 29% (±36%) per event, while SF was observed during 124 events and on average represented 0.02% (± 0.09%) of rainfall in the open. Pine tree intercepted on average 73% of rainfall in the open, with minimal difference between the phenoseasons (69% and 74% in leafless and in leafed period, respectively).

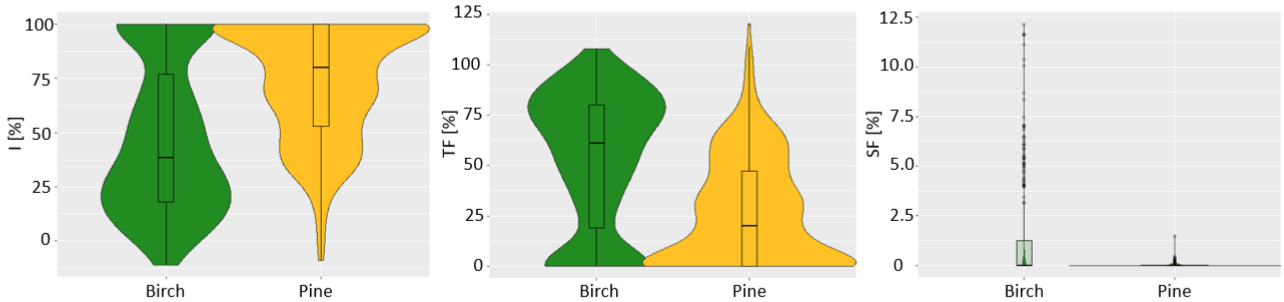
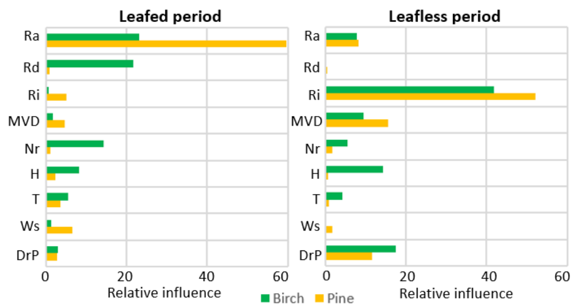


Fig. 1 Measured rainfall interception (I), throughfall (TF) and stemflow (SF) by birch and pine trees per rainfall event

The amounts of rainfall partitioning correspond to different combinations of influencing variables. To analyze proportions of rainfall interception by birch and pine trees, the influence of numerous variables per phenoseasons and per dry and wet years were modelled by generalized boosted regression tree models (BRT) and correlation matrices. Year 2014 was treated as a wet and year 2015 as a dry year according to the comparison of the annual rainfall amounts per long term average (Zabret and Šraj, 2019). The results of BRT show, that rainfall interception by both, birch and pine trees is the most influenced by rainfall amount in leafed period and by rainfall intensity in leafless period (Fig. 2). According to the meteorological characteristics during the phenoseasons we can compare leafed season with drier and leafless season with wetter conditions. Similarly, during the wet year of 2014, rainfall interception by both tree species was the most influenced by rainfall amount, intensity and duration, while in year 2015 (dry year) influence of rainfall intensity was negligible (Fig. 2).



2014 (wet year)

	I birch	Ra	Ri	Rd	Ws	T	H	DrP
I pine	1	0.66	0.42	0.4	0.19	0.09	0.15	0.07
Ra	0.95	1	0.34	0.8	0.15	-0.1	0.25	0.24
Ri	0.35	0.34	1	-0.11	0.41	0.23	-0.16	-0.03
Rd	0.74	0.8	-0.11	1	-0.14	-0.2	0.24	0.28
Ws	0.14	0.15	0.41	-0.14	1	0.23	-0.44	0.14
T	-0.1	-0.1	0.23	-0.2	0.23	1	-0.41	0.05
H	0.29	0.25	-0.16	0.24	-0.44	-0.41	1	-0.09
DrP	0.2	0.24	-0.03	0.28	0.14	0.05	-0.09	1

2015 (dry year)

	I birch	Ra	Ri	Rd	Ws	T	H	DrP
I pine	1	0.71	0.02	0.64	0.17	-0.15	0.14	-0.01
Ra	0.72	1	0.25	0.76	-0.03	-0.24	0.31	-0.06
Ri	-0.03	0.25	1	-0.22	0.13	0.39	-0.32	0.36
Rd	0.76	0.76	-0.22	1	-0.08	-0.27	0.31	-0.25
Ws	0.07	-0.03	0.13	-0.08	1	0.2	-0.59	0.23
T	-0.24	-0.24	0.39	-0.27	0.2	1	-0.57	0.02
H	0.19	0.31	-0.32	0.31	-0.59	-0.57	1	-0.22
DrP	-0.03	-0.06	0.36	-0.25	0.23	0.02	-0.22	1

Fig. 2 Results of BRT (left) and correlation matrices (right) on influence of meteorological variables on rainfall interception

Conclusions

Long-term continuous measurements of TF, SF and meteorological variables was analyzed with two statistical methods to show which variables influence the rainfall partitioning the most and how is their impact connected to general weather conditions. The comparison of results for wet and dry year and wet and dry phenophase showed that in wetter conditions rainfall intensity play significant role while in drier conditions it has negligible impact as rainfall amount and duration were recognized as the most influential. The comparison of the results indicate that the influence of general weather conditions dominates the properties of tree canopy.

References

R core team (2020) R: A language and environment for statistical computing. http://www.R-project.org/ (Accessed August 20, 2020)

Staelens J, De Schrijver A, Verheyen K, Verhoest NEC (2008) Rainfall partitioning into throughfall, stemflow, and interception within a single beech (*Fagus sylvatica* L.) canopy: influence of foliation, rain event characteristics, and meteorology. *Hydrological Processes,* **22**, 33–45.

Šraj M, Brilly M, Mikoš M (2008) Rainfall interception by two deciduous Mediterranean forests of contrasting stature in Slovenia. *Agricultural and Forest Meteorology,* **148**, 121–134.

Van Stan JT, Van Stan JH, Levia DF (2014) Meteorological influences on stemflow generation across diameter size classes of two morphologically distinct deciduous species. *International Journal of Biometeorology* **58**, 2059–2069.

Zabret, K (2013) The influence of tree characteristics on rainfall interception. *Acta hydrotechnical* **26**, 99−116.

Zabret K, Rakovec J, Šraj M (2018). Influence of meteorological variables on rainfall partitioning for deciduous and coniferous tree species in urban area. *Journal of Hydrology*, **558**, 29–41.

Zabret K, Šraj M (2019) Rainfall Interception by Urban Trees and Their Impact on Potential Surface Runoff. Clean, 1800327.

Rainfall interception from the erosivity perspective

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Introduction

Rainfall erosivity is one of the main drivers of the soil erosion processes that can cause several environmental problems. Moreover, rainfall erosivity is characterized by large spatial and temporal variability (e.g., Bezak et al., 2020; Bezak et al., 2021). Therefore, investigations related to the drivers of rainfall erosivity and impact factors that are related to the rainfall erosivity are needed in order to enhance the knowledge about it. Rainfall interception due to the vegetation is a main driver of the reduction of the rainfall erosive power. In order to calculate rainfall erosivity different methods can be employed where the simplest ones are based on the annual or daily rainfall amounts, the more sophisticated ones or the more correct ones need detailed high-frequency measurements of the drop-size distribution (DSD) data (Petan et al., 2010). This kind of data can be nowadays obtained using optical disdrometer measurements that are able to detect the number of raindrops and classify them into classes based on their velocity and drop diameter. The main objective of this study is to evaluate the influence of the rainfall interception on the rainfall erosivity.

Methodology

This research is based on the precipitation measurements in the period of 14 months (in years 2017 and 2018) using two disdrometers located above and below the birch tree canopy (OTT Parsivel). The location of the study area is the urban park in the city of Ljubljana (e.g., Zabret et al., 2018). Firstly, erosive rainfall events were determined according to the RUSLE methodology (e.g., Renard et al., 1997) from the obtained data. Then we calculated the duration of individual events, the accumulated rainfall amount and determined the drop size, velocity and number of raindrops detected above and below the canopy. We also calculated the kinetic energy of rainfall and the rainfall erosivity factor R of the RUSLE methodology (Renard et al., 1997). For the calculation of the kinetic energy that is need to calculate R factor next equation was applied:

$$KE(dsd) = \frac{\pi \cdot \rho}{12 \cdot 10^3 \cdot F \cdot \Delta t} \cdot \sum_i n_i \cdot \frac{1}{D_{b,i} - D_{a,i}} \cdot \int_{D_{a,i}}^{D_{b,i}} D_i^3 dD \cdot \frac{1}{v_{b,i} - v_{a,i}} \cdot \int_{v_{a,i}}^{v_{b,i}} v_i^2 dv \qquad (1)$$

where ρ is water density, F is disdrometer measuring area, n is number of detected raindrops in class i, D_a and D_b are drop size classes limits, v_a and v_b are velocity classes limits (Zore, 2020). Details above the applied methodology are provided by Zore (2020).

Results and conlusion

The results show that throughfall under the birch tree is increasing with a duration of the event. The interception by the birch canopy was 33% of precipitation during the vegetation period (leafed period), and 25% during the dormant period (leafless period). Raindrop sizes and velocities were generally higher above the canopy than below it throughout the period considered, but they largely retained their size and velocity as they passed through the canopy during the dormant period. The kinetic energy of raindrops was maintained during the dormant period as they passed through the canopy, while it decreased by 31% during the vegetation season.

During the vegetation period, the rainfall erosivity factor R decreased by 50% after raindrops passing through the canopy, and during the dormant period the value under the canopy decreased by 21%. Some preliminary graphical results are provided in Fig.1-Fig.3.

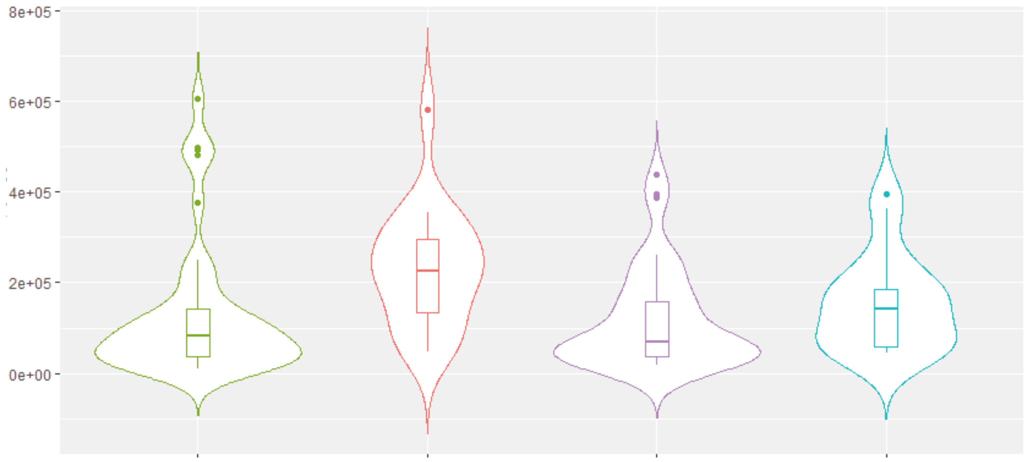

Fig. 1 Number of detected raindrops (y-axis) above (left two violin plots; green-leafed period; red-leafless period) and below tree crown (right two violin plots; purple-leafed period; blue-leafless period).

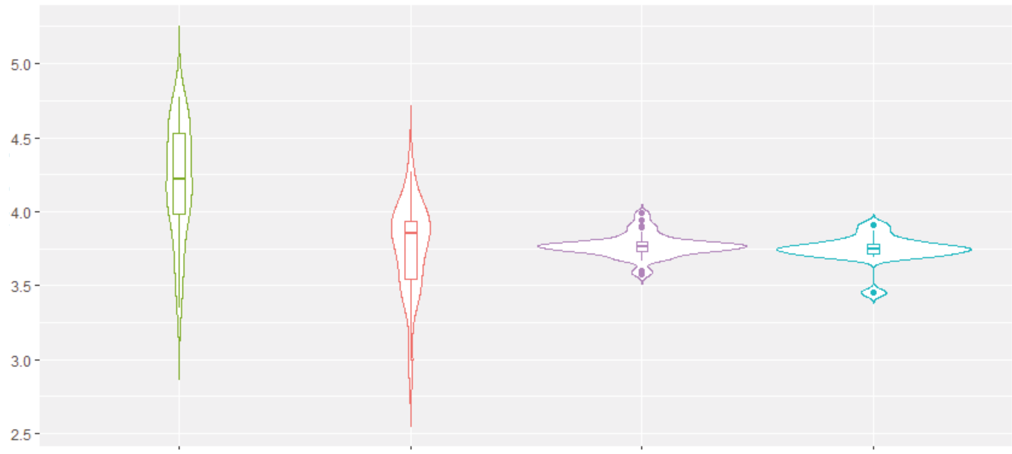

Fig. 2 Raindrop velocity [m/s] (y-axis) above (left two violin plots; green-leafed period; red-leafless period) and below tree crown (right two violin plots; purple-leafed period; blue-leafless period).

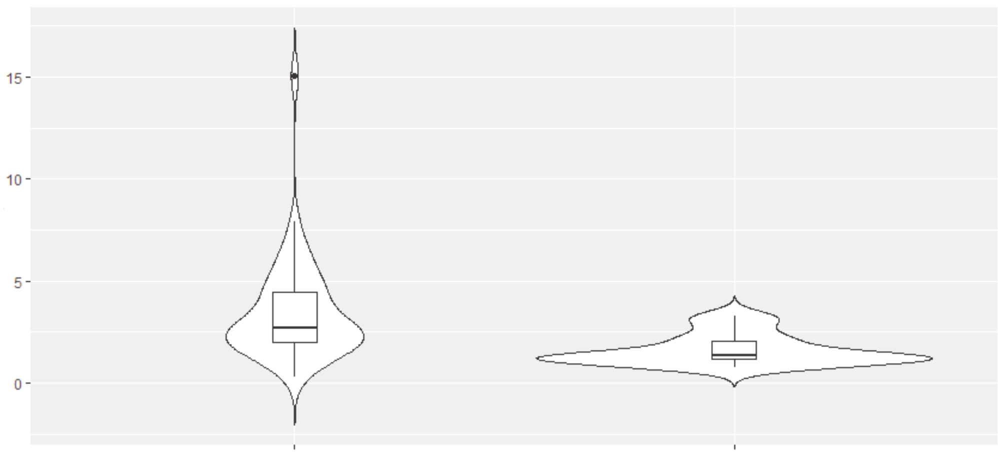

Fig. 3 Ratio between R above tree canopy and R below tree canopy (y-axis) for the leafed period (left figure) and leafless period (right figure).

Acknowledgements

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References

Bezak N, Ballabio C, Mikoš M, Petan S, Borrelli P, Panagos P (2020) Reconstruction of past rainfall erosivity and trend detection based on the REDES database and reanalysis rainfall, *Journal of Hydrology*, **590**, 125372.

Bezak N, Borrelli P, Panagos P (2021) A first assessment of rainfall erosivity synchrony scale at pan-European scale, Catena, 198, 105060.

Petan S, Rusjan S, Vidmar A, Mikoš M (2010). The rainfall kinetic energy–intensity relationship for rainfall erosivity estimation in the mediterranean part of Slovenia, *Journal of Hydrology*, **391**, 314–321.

Renard, KG, Foster GR, Weesies GA, McCool DK, Yoder DC (1997) Predicting Soil Erosion byWater: A Guide to Conservation Planning with the Revised Universal Soil Loss Equation (RUSLE) (Agricultural Handbook 703).

Zabret K, Rakovec, J, Šraj M (2018). Influence of meteorological variables on rainfall partitioning for deciduous and coniferous tree species in urban area, *Journal of Hydrology*, **558**, 29–41.

Zore A (2020). Influence of rainfall interception on the soil erosion, Master Thesis. Available at: https://repozitorij.uni-lj.si/IzpisGradiva.php?id=123332&lang=slv.

Topic 3

New developments in hydrological forecasting and enabling hydrological work in the Danube catchment

Developing probabilistic long-term forecasts for the upper Danube waterway

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Introduction

Many sectors, such as hydropower, agriculture, water supply and waterway transport, require information about the possible evolution of meteorological and hydrological conditions within the next weeks and months to optimize their decision processes on a long term. With increasing availability of meteorological seasonal forecasts, hydrological seasonal forecasting systems have been developed all over the world within the last years.
Currently, the German Federal Institute of Hydrology (BfG) is providing 2–4 days forecast for the upper Danube from gauge Pfelling to gauge Vilshofen on an operational, daily basis, which is published via the German River Information Service ELWIS. Since March 2019 we are also providing pre-operational 6-week-forecasts for the gauges Pfelling and Hofkirchen twice a week. This forecast, which also covers gauges at Rhine and Elbe, is available for registered users and still in an experimental state. Due to the great uncertainties attached to a forecast of this temporal scale, the prototypical product contains weekly streamflow and water level means. In addition, the forecast is interpreted in relation to the observed long-term streamflow for a better understanding of the upcoming situation.
First hindcast analyses (figure 1) show, that the forecast already has skill for the first three weeks during the whole year even in this early state without proper post processing or data assimilation. There are some times of the year with higher skill for a longer forecasting period. For example, a forecast initialized in April shows skill up to 6 weeks, due to the yearly snow melting season. Currently, we are working on post processing methods to further improve the forecast skill. The first outcomes using EMOS (ensemble model output statistics) (Gneiting et al., 2005 and Hemri & Klein, 2017) are promising. Additionally, future activities are scheduled in the context of data assimilation techniques and hydrological model improvements.

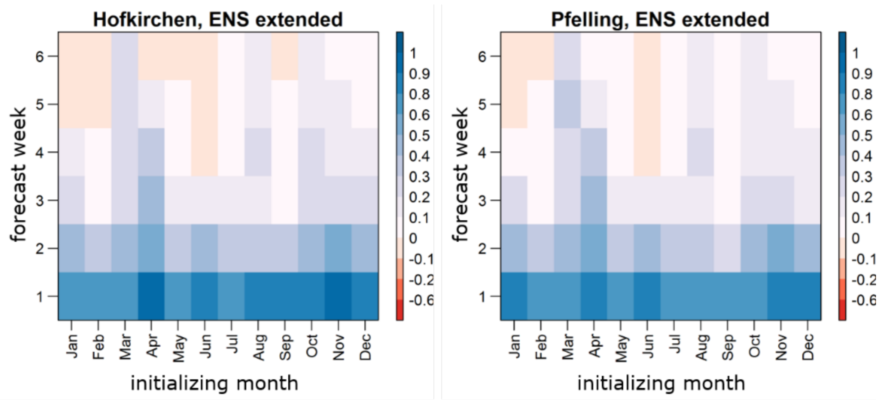

Fig. 1 Monthly continues ranked probability skill score (CRPSS) (Ferro et al., 2008) for gauge Hofkirchen and Pfelling, calculated based on ECMWF-ENS extended reforecasts from 2000 to 2016.

Methodology

The technical workflow is shown in figure 2. The 6-week-forecast is based on the ECMWF-ENS extended data, which is a meteorological ensemble forecast including 51 members for the upcoming 46 days (Owens & Hewson, 2018). This data is downscaled to a 5 x 5 km grid on which the hydrological model operates. The applied model is the water balance model LARSIM-ME (Ludwig & Bremicker, 2006) calibrated by BfG with the HYRAS data (Rauthe et al., 2016) from the German National Meteorological Service (DWD). This data is also used for a second type of hydrological forecast, the ensemble streamflow prediction (ESP) approach (Wood & Lettenmaier, 2008) which also includes 51 members. Observed meteorological data from DWD and CHMI is interpolated to the 5 x 5 km grid and used to initialize the model. The daily streamflow model output is processed to weekly means for the trend forecast. The user receives a report based on water level or streamflow. The water level is simply calculated with the current stage-flow relationship which is sufficient, due to the temporal resolution of the forecast. In addition to an advanced post processing of the hydrological forecast, the use of the ECMWF-ENS extended reforecasts for an operational drift correction of the meteorological forecast is scheduled.

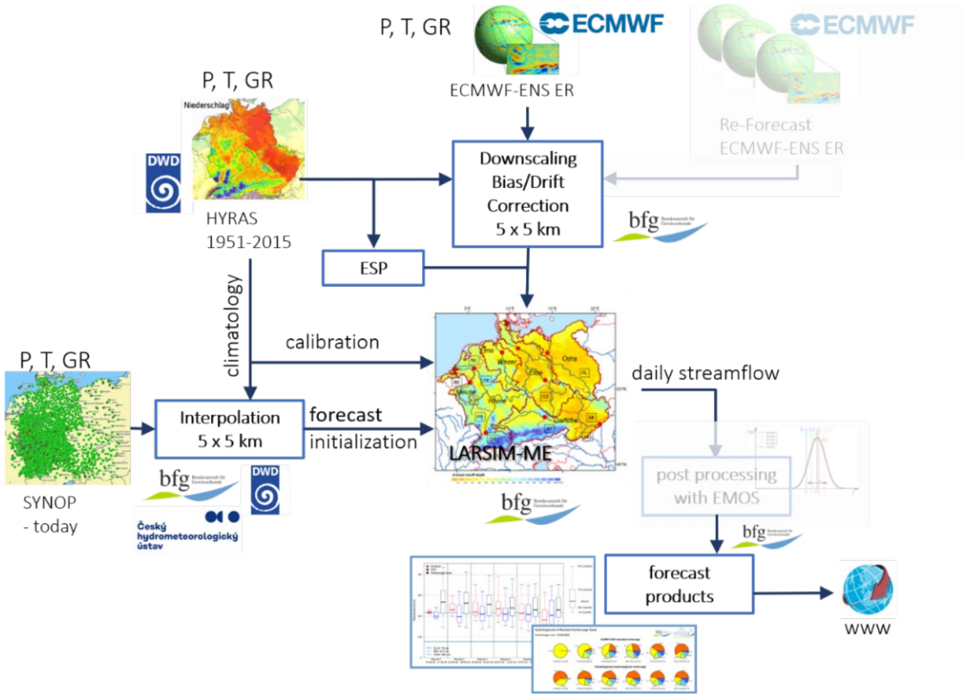

Fig. 2 Technical workflow of the 6-week-forecast. Including the ECMWF-ENS extended reforecasts and post processing using EMOS in the process is in planning.

Conclusion / Outlook

Running the forecast pre-operational for the last two years showed that it is well received among the users. A regular exchange between users and developers is crucial for a successful product. Based on such exchange we are planning to provide an interactive tool with customizable graphics for a threshold-based forecast for example. Additional scheduled steps are: an operational drift correction, using the ECMWF-ENS extended reforecasts (Owens & Hewson, 2018), and an advanced post processing with EMOS (Gneiting et al., 2005 and Hemri & Klein, 2017). Both methods seems to be promising to improve the forecast.

References

Ferro C A T, Richardson D S, Weigel A P (2008): On the effect of ensemble size on the discrete and continuous ranked probability scores, *Meteorological Applications* **15** (1), 19–24

Gneiting T, Raftery A E, Westveld A H, Goldman T (2005): Calibrated probabilistic forecasting using ensemble model output statistics and minimum CRPS estimation, *Monthly Weather Review* **133** (5), 1098–1118

Hemri S, Klein B (2017): Analog-Based Postprocessing of Navigation-Related Hydrological Ensemble Forecasts, *Water Resources Research* **53** (11), 9059–9077

Ludwig K, Bremicker M (2006): The Water Balance Model LARSIM – Design, Content and Applications, Institut für Hydrologie, Universität Freiburg im Breisgau, Freiburg

Owens R, Hewson T R E (2018): ECMWF Forecast User Guide, ECMWF, Reading

Rauthe M, Steiner H, Riediger U, Mazurkiewicz A, Gratzki A (2013) A Central European precipitation climatology – Part I: Generation and validation of a high-resolution gridded daily data set (HYRAS), *Meteorlogische Zeitschrift*, **22** (3), 235–256

Wood A W, Lettenmaier D P (2008): An ensemble approach for attribution of hydrologic prediction uncertainty. *Geophysical Research Letters*, **35** (14)

Possibilities of controlling the storage function of the reservoir using a combination of dispatching graphs and a prediction model.

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Abstract

The control described in the article examines the possibilities of using a combination of prediction models and the method of dispatching graphs. Based on the forecast, controlled water outflows from the reservoir are adjusted. The controlled outflows are given by individual stages of control by the method of dispatching graphs. The method itself was applied to the Vranov reservoir on the river Dyje (Czech Republic). In the application of the above mentioned procedure, better results of the selected criteria were achieved when using a combination of forecast and dispatching graphs than when using the dispatching graphs themselves.

Introduction

In the years 2016–2019, the territory of the Czech Republic was affected by a long and significant drought, which had a great impact on the water levels of the river network and the groundwater level. Flows in most of the observed profiles fell well below the drought limit. An exception was the profiles under the reservoirs, where the flows at the boundary of the hydrological drought were improved by the reservoirs. During the long drought, storage volumes dropped significantly or, in the case of some reservoir, the values of storage volumes were completely depleted. In the case of the Vranov reservoir, extraordinary manipulation took place in the autumn of 2018, which was not completed until the spring of 2019. In the Czech Republic, dispatching graphs are used to control the storage function of the reservoir (Broza, 1981). The dispatching graphs themselves are a very effective tool for controlling the storage function of the reservoir if there is a relatively regular hydrological cycle at the inflows to the reservoir. The proposed procedure in the article is based on dispatching graphs taken from the Vranov reservoir handling rules (Vranov, 2011) and a deterministic prediction model based on a fuzzy learned model and interval of expected future occurrences of flows (Kozel and Stary, 2021). Based on the results of the prediction model, controlled water outflows from the tank will be adjusted.

Methods

The control model is based on a combination of dispatching graphs compiled on a real series and a prediction model. The procedure itself is considered in a monthly step. The control module consists of a prediction model that provides a prediction vector $\boldsymbol{Qp}$ and its own control algorithm. The algorithm at the beginning of each control step determines the degree of the dispatching graph based on the value of the storage volume at the beginning of the step. The DG level determines the value of the controlled outflow of water from the tank. Subsequently, a control simulation is performed. At the end of the control simulation, the value of the storage volume is determined and the DG level is determined. If the prediction vector is longer than 1, the controlled outflows for other members are considered from the DG level determined at the beginning of the calculation step. If there is a change in the DG level, proceed according to Table 1 is used.

Tab. 1 Rules for control outflow O1

DG current level – DG level on simulation end	Control outflow O1
-2 and less	O1= (O1a + O1a-1)/2
-1	O1= O1a - (O1a - O1a-1)/5
0	O1 =O1
1 and more	O1= O1a + (O1a+1 - O1a)/5

Application

The Vranov reservoir was selected for the application of the method described above (The value of the storage volume is 78,900,000 m^3). The reservoir was selected based on data availability and the problems it faced during the 2016–2019 drought. The values of target outflow were taken from the handling rules of the Vranov reservoir (Vranov, 2011). The success of the control itself is assessed on the basis of the criterion π, which is calculated as the sum of the squares of the deviations between the control and controlled outflows. Figure 1 shows the results of the control provided by the combination of DG and forecast (best result, length =5) and the results obtained using the DG method and control effluents.

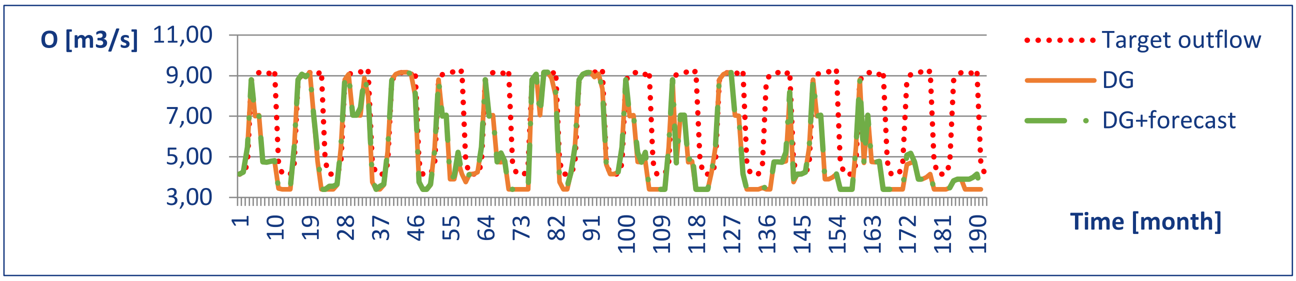

Fig. 1. Results of DG method, DG + forecast and target outflow during validation period.

Results

From the above results, it is clear that the combination of the prediction model and the DG method is able to achieve good results. The best results of the criterion were achieved for the length of the forecast 5 months ($\pi = 1341$). The results of the combination alone achieved better results than the control alone using the DG method ($\pi = 1409$). Thanks to the use of a prediction model, the control is able to react earlier to the occurrence of long and dry periods, the introduction of a reduction in controlled runoff. Conversely, the information provided by the prediction model may lead to a mitigation of the established failure.

Acknowledgement

The article was supported by grant Possibilities of improving water quality in watercourses at low water levels FAST-S-21-7482.

Reference

Broža V., 1981: Metodické návody k vodohospodářským řešením nádrží, ČVUT v Praze, Praha, 1981

Manipulační řád pro VD Vranov, 2011, s. 1–77.

Kozel T., Stary M., 2021: Adaptive management of the storage function for a large reservoir using learned fuzzy models, Water Resources,Pleiades Publishing, Ltd. ISSN PRINT: 0097-8078, ISSN ONLINE: 1608-344X.

WEB.BM – Introducing a new tool and a new paradigm for using optimization to revise reservoir operating rules and improve real time operation

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Abstract

We introduce WEB.BM – a new web-based modeling tool for multi-purpose multi-reservoir river basin management based on Mixed Integer LP solver that can optimize basin operation over single or multiple time steps. The model can include flexible time step length and optional use of reservoir and hydrologic channel routing built as LP constraints. WEB.BM includes the most common river basin management components and constraints such as reservoirs, hydro power, environmental flow targets, return flows from irrigation, diversion volume licenses, apportionment agreements between neighboring states and net-evaporation. The model is created using .NET Core technology with MS SQL database and Google Maps interface. It is accessible free of charge at www.riverbasinmanagement.com as a planning tool or a short-term operational model where runoff forecasts are available. The priority among different users is represented by a proper selection of weight factors which are user defined. So far, the model has been used in Western Canada, India and Serbia. The paper describes the process of building input data, conducting long term reservoir optimization to help revised reservoir operating rules, and mocks the implementation of these revised rules in an environment where short term runoff forecasts of up to 2 weeks are combined with using optimization modeling to improve the real time operation. The model is demonstrated on a small system or river Uvac in Serbia that consists of three dams and their hydro power plants.

Keywords: Real Time Reservoir Operation, Reservoir Operating Zones, Multiple Time Step Optimization.

Introduction

Recent decades have seen an explosion of all sorts of modelling tools, which are used for various purposes in water resources sector. River basin modeling has become an integral part of river basin planning studies, be it for studying mitigation of floods, or developing measures to combat droughts. This paper deals with river basin management models, which can be defined as models that find the most suitable set of reservoir releases and water abstractions for a given time period, subject to physical and operational constraints. The use of optimization algorithms as part of the 'solution engines' within these models has proven to be a valuable technique, given the complexity of the problem of finding the best set of reservoir releases in multi-reservoir river basins operated for multiple purposes. Although river basin management models have so far largely been used as river basin planning tools, recent development of remote sensing satellite technologies coupled with improvement in the capabilities of runoff forecasting models hold out a promise for their application as real time operational tools in the near future. The paper is structured in the following way literature review is included in Section 1; importance of developing historical natural flows and their use for planning purposes is outlined in section 2, which outlines the need to define a verification scenario as a foundation for any future benchmark simulation runs; 3 the available optimization options are outlined in section 3 and the results of the case study are formulated in section 4. Section 5 includes conclusions and recommendations, followed by the references.

Section 2. Development of Historical Natural Flows

The process of naturalizing historical flow records involves undoing the effects of regulation. This is achieved by reversing the effects of storage change and diversion from the stream by starting from the most upstream control points and by moving reach by reach in a downstream progression. For example, assuming that inflow into a reservoir comes from two streams that have their natural flows designated as Q_1 and Q_2, the natural flow at the downstream reservoir R can be calculated by using the following expression:

$$Q_R = Q_1 + Q_2 + LR \tag{1}$$

Where the term LR represents local runoff from a sub-catchment delineated by locations where natural flows Q_1 and Q_2 are known and the downstream point of interest (in this case a reservoir). The term LR is calculated by using:

$$LR = \sum_{i=1}^{m} Q_i - \sum_{j=1}^{n} Q_j + \frac{\Delta V}{t} \qquad (2)$$

where:

- Q_i average outflows (i=1,m) from a sub catchment within time step t
- Q_j average inflows (i=1,m) into a sub catchment within time step t
- $\Delta V/t$ total storage change within the sub-catchment area in time step t

This approach can be applied only on gauged basins where storage change, inflows into and out of each sub-catchment areas are based on the flow records. While many river basins have sufficient information to enable this kind of assessment, the old approach to resort to rainfall-runoff modelling so as to estimate the available runoff is still dominant, although in the validation stage the simulated output shows significant discrepancies when compared to the historic flow records.

Section 3. Use of Optimization in River Basin Modeling

River basin models have typically relied on the use of reservoir rule curves. Those are target reservoir levels for the end of each week provided by the user as part of input data, and they are used repeatedly in each simulated year, although the starting reservoir levels in each year are different, and so is the incoming hydrology. This paper demonstrates that optimization can and should be used to develop reservoir operating zones, which should replace the rule curves. It also shows, that it can be very effective in real time operation, assuming short term runoff forecasts are available. The ultimate utility of this approach is demonstrated by comparing the historic operation with the simulated operation based on assuming that short term runoff forecasts are available.

Section 4. Cast Study

The case Study includes three hydro power plants located on the River Uvac in Western Serbia. The entire process outlined in the paper is applied to demonstrate the potential improvements in generated hydro power compared to the historical operation.

Literature

N. Ilich, A. Basistha (2021): Importance of multiple time step optimization in river basin planning and management: a case study of Damodar River basin in India, Hydrological Sciences Journal, DOI:10.1080/02626667.2021.1895438.

Ilich, N., 2013. An effective three-step algorithm for multi site generation of weekly stochastic hydrologic time series. *Hydrological Sciences Journal*, **59** (1-2), 85–98. Doi:10.1080/02626667.2013.822643.

Comparison of simulated discharge over Ogosta river basin using ground, satellite and merged data as precipitation input for the purpose of flood forecasting

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Introduction

The hydrological processes are very complex and the hydrological and hydraulic models are the main components of the flood forecasting and warning systems. They identify the dominant hydrological processes which influence water balance and result in conditions of extreme hydrological events. A variety of hydrological models (lumped, semi-distributed, distributed) exist nowadays. In this study the physically-based, fully distributed hydrological model TOPKAPI (TOPographic Kinematic APproximation and Integration) is applied. The model utilities three non-linear reservoir differential equations for the drainage in the soil, the overland flow on saturated or impervious soil, and the channel flow along the drainage network (Yordanova et.al., 2017). The model was successfully applied over two basins in Bulgaria – Ogosta river basin with attempt to include the management of big reservoir (Yordanova, Stoyanova, 2020), and Aytoska river basin with meteorological stations outside of the watershed (Yordanova, Stoyanova, 2020).
The precipitation has high spatial variability especially in convective events. The conventional methods of measuring the precipitation is using rain-gauges, which are sometimes more than 30 km from one another. Thus it is of great importance to have precipitation in denser points especially in convective events as the one, which will be presented in this study (01 – 03 June 2019). One possible solution for denser estimates of the precipitation is to merge conventional with satellite data.

Methodology

In this paper for the model simulations are used interpolated data at the locations of the 21 meteorological stations used for the model calibration (Fig. 1). The following type of precipitation inputs will be used:

- Data from conventional stations;
- Data from automatic stations interpolated into the 21 meteorological stations used for the model calibration;
- Data from HSAF project. H05b product is selected for this paper. This is Accumulated precipitation by merging MW images from operational sun-synchronous satellites and IR images from GEO satellites (i.e., product P-IN-SEVIRI) (hsaf.meteoam.it). The data from this product are again interpolated in the locations of the 21 meteorological stations;
- Merged data from automatic stations and H05b product, interpolated in the locations of the 21 meteorological stations using kriging method Generalized Additive Model (GAM) (Webster and Oliver, 2001).

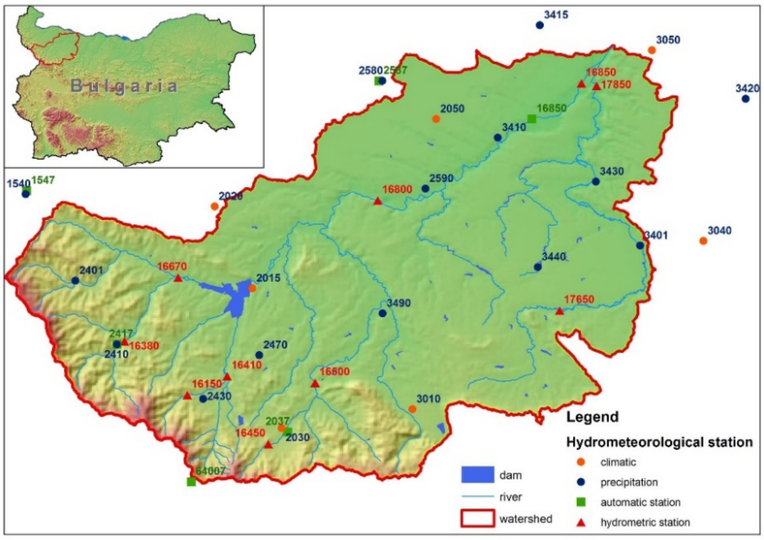

Fig.1 Ogosta river basin, meteorological stations, hydrometric stations, DEM (digital elevation model) and the river network

Results

On Fig. 2 are shown the results from the different simulations at 3 of the gauging stations. Two of them – 16380 and 16670 are located in the upper part of basin, above the damn, and the 3rd station, 16850, is located at the outlet of the basin.

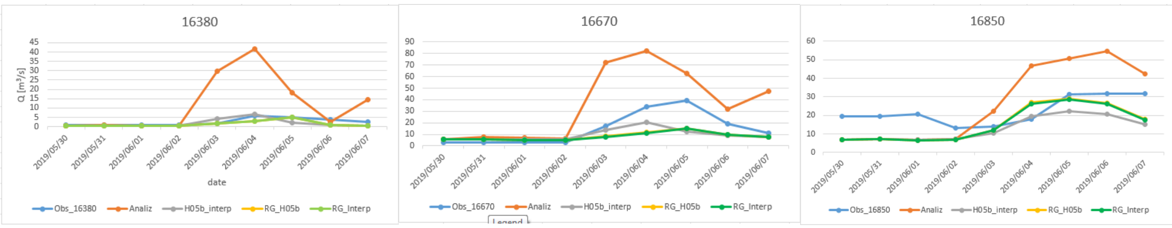

Fig. 2 Simulation results with different precipitation inputs VS observed discharge (blue): red - precipitation from conventional station; grey –interpolated data from HSAF product; green –interpolated data from automatic rain gauges; line –interpolated data from automatic data and HSAF product.

The results show that the model overestimates the peak discharges, when simulations are performed with conventional ground data. It is also seen that the simulation with satellite product generally underestimates the discharge. The simulations with interpolated data from automatic stations also show better simulation simulations in the lower part of the basin. This could be explained with the fact that in the lower part of the country there are more automatic stations than in the upper (mountainous) part, which leads to better distribution of the rainfall in the lower part of the basin.

Conclusions

The results from this study show that the data from the HSAF cannot be applied alone for hydrological modelling especially in case of simulation of floods. Better results are achieved when using combination of satellite and ground data.

In this paper the simulations are performed on a 24 hours time step and the simulation results are compared with observed discharges at 8 o'clock in the morning. This is quite big step, especially when simulating and forecasting flash floods (which range is usually less than 10 hours). Our future work will be focused in decreasing the time step in order better simulation of the time and magnitude of the flood peaks.

References

http://hsaf.meteoam.it/Products/ProductsList?type=precipitation

Yordanova VI, Balabanova SS, & Stoyanova VT (2017). Application of the TOPKAPI model on the Ogosta river basin. In 17th Conference of the Danubian countries on Hydrological Forecasting and Hydrological bases of Water Management, Bulgaria, Electronic book with full papers (pp. 357–364).

Yordanova VI, Stoyanova, SV (2020). IMPROVED EXTREME FLOW MODELING BY RESERVOIR MANAGEMENT INPUT USING A PHYSICALLY BASED HYDROLOGICAL MODEL: A CASE STUDY OF OGOSTA RESERVOIR IN OGOSTA RIVER BASIN. International Multidisciplinary Scientific GeoConference: *SGEM*, **20**(3.1), 185–191.

Yordanova VI, Stoyanova, VT (2020). MODELING FLOODS WITH A DISTRIBUTED HYDROLOGICAL MODEL IN A RIVER CATCHEMENT. International Multidisciplinary Scientific GeoConference: *SGEM*, **20** (3.1), 249–255.

Webster R, Oliver MA (2001) Geostatistics for environmental scientists. Statistics in practice series Chichester: Wiley.

Possibilities of using neural networks for data preprocessing in models predicting flash floods

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Introduction

In recent years, the occurrence of flash floods in the Czech Republic has been quite common. Flash floods themselves are characterized by high precipitation totals in a very short time in a small area. From the point of view of early warning systems, they are a very problematic phenomenon, because between the beginning of the causal precipitation and the culmination reaction of the basin, there is relatively little time to issue a warning and possible evacuation. For the above reason, an effort is made to predict these phenomena using different models. The fuzzy flash flood model FFF (Janal and Stary, 2012) is one of the ways to effectively predict flash floods. Models for predicting the danger of torrential rains use nowcasting, which is based on predictions based on radar observations or adjusted radar observations. The adjustment coefficients themselves are calculated retrospectively on the basis of the previous measured precipitation and are valid until the issue of new adjustment coefficients. From the point of view of nowcasting, a problem arises where the adjustment of extreme values of precipitation totals is therefore adjusted only after their measurement. From the point of view of flash floods, the above-mentioned extreme values are critical, and therefore it is necessary to create a tool for an approximate estimation of the error between radar observations and the values actually measured. The need to improve the inputs to the FFF model arose from an evaluation of the success of the FFF model (Janal and Kozel, 2019), when the FFF model reached too many false alarms for the period under review (the model issued a warning but nothing actually happened). For this purpose, the article describes a method based on the method of neural networks (Jang and Sun, 1995), where neural networks themselves are a very suitable means of finding strongly nonlinear dependencies, as has been proven by many authors (Nayak et. All, 2005; Lin et. All, 2020; Kozel and Stary 2019)

Methods

For the possibility of testing the possibilities and limit for preprocessing based on neural networks, records were selected from a total of 229 precipitation stations for the years 2016–2020. When the years 2016–2019 were used for model calibration and the year 2020 for validation. A large square (5x5) is chosen for each station, which consists of sub-squares of the grid with a square size of 1 000 x 1 000 m. The method was chosen due to the fact that radar-measured values do not always fall into the same grid square in which it is measurement performed. From the above statement it can be stated that the measured values in the station (merge) and the values obtained with the help of radar may not correspond directly in the square of the grid where the precipitation station is located, but will most likely be interdependent in the vicinity of the precipitation station. The model itself was trained only in places of rain gauge stations, where it is possible to quantify errors, but its use will be tested throughout the Czech Republic.
The preprocessing itself will be applied to the 1st value of the sum of hourly precipitation totals. Due to the huge amount of data, a simplification will be adopted when creating a preprocessing model in the form of working with data in an hourly step. For the training itself, the hourly sums of radar measurements and the hourly sums of precipitation totals obtained by measurements at the station will be used. In real operation, the FFF model calculates the risk of the river basin in a 5-minute step (radar step). This means that the preprocessing results will be valid for the entire following hour.
In the second step, resimulation of events for which the impact was determined on the basis of the evaluation will be performed on selected situations from 2020. During resimulation, both preprocessed values and original values will be used by the FFF model.

Conclusion

The aim of the nowcasting value preprocessing application is to refine the input for models that work with flash floods. This refinement of the input could lead to a reduction in the number of false alarms (expected values of precipitation totals are strongly overestimated). The second expected impact could be a reduction in the occurrence of miss alarms (expected values of precipitation totals are significantly lower than the reality) and thus reduce the negative impacts of these events.

Acknowledgements

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References

Janal, P., Stary, M., 2012. Fuzzy model used for the prediction of a state of emergency for a river basin in the case of a flash flood - PART 2. *Journal of Hydrology and Hydromechanic*, **60**, 3, 162–173.

Janal, P. and Kozel, T, 2019. Fuzzy logic based flash flood forecast, XXVIII CONFERENCE OF THE DANUBIAN COUNTRIES ON HYDROLOGICAL FORECASTING AND HYDROLOGICAL BASES OF WATER MANAGEMENT, Kyiv, Ukraine, DOI: 10.15407/uhmi.conference.01.10

Jang, J. S. R. and Sun, C. T., 1995. "Neuro-Fuzzy Modelling and Control", Proceedings of the IEEE, vol. 83, no. 3, pp. 378-406, Mar. 1995. doi:10.1109/5.364486

Kozel, T., Stary, M., 2019. Adaptive stochastic management of the storage function for a large open reservoir using an artificial intelligence method. *J. Hydrol. Hydromech.*, Vol. **67**, No. 4, 2019, p. 314–321, doi: 10.2478/johh-2019-0021

Lin, Q., Leandro, J., Wu, W., Bhola, P. and Disse, M., 2020. Prediction of Maximum Flood Inundation Extents With Resilient Backpropagation Neural Network: Case Study of Kulmbach. Front. Earth Sci. 8:332. doi: 10.3389/feart.2020.00332

Nayak, P., Sudheer, K., Rangan, D., and Ramasastri, K., 2005. "Short-term flood forecasting with a neurofuzzy model," Water Resources Research, vol. 41, no. 4, 2005. doi:10.1029/2004WR003562

Implementation of a Long Short-Term Memory Neural Network based hydrological model in a snow dominated Alpine basin

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Introduction

The melting of snow and ice in high altitude region of the Alps in the past has formed several drainage basins, which are nowadays important both for the Alpine region and downstream areas. Some of the largest European rivers, such as Danube, Rhine, Sava, etc., have their origin in the Alps. The runoff regime of the Alpine mountain rivers is driven by a combination of precipitation and snow and ice melt, so in order to understand and predict runoff regime under different weather conditions it is important to obtain reliable measurements and observations of different hydrometeorological parameters. The high altitude and remote regions are usually inaccessible and a smaller density of in-situ stations has been complemented over the time with the remote sensing information. With the development of data transmission and processing techniques, the speed and accuracy of in remote sensing data have been continuously increasing. The application of remote sensing in collecting precipitation data (Duan et al., 2016; Tuo et al., 2016) and snow and ice cover data (Tekeli et al., 2005) in mountainous regions has become widely accepted. However, further validation of precipitation and other products are still recommended with the aim of a more detailed comparison and evaluation.

Runoff models can be divided into energy-based models, temperature index (degree-day) models and, data-driven models (Thapa et al., 2020). Despite the importance of the European Alps, studies on snowmelt-runoff and/or rainfall-runoff modelling based on data-driven models are rare. This paper presents an implementation of a data-driven modelling approach based on artificial neural networks (ANN) with Long Short-Term Memory (LSTM) architecture in a mountainous basin in Tyrol, Austria (and partly Italy).

Methodology

Study area

For this study the Drava river basin upstream of Lienz is chosen. With a drainage area of 669.35 km^2 and elevation range from 666 to 3056 m a.s.l. this basin represents a typical smaller mountain basin. Despite the high altitude and remoteness, several meteorological measuring stations are present in and around the basin.

Artificial Neural Networks

"*An artificial neural network is a massive parallel distributed data processing system that consists of simple processing units, with a natural propensity of storing experimental knowledge and making it available for use.*" (Haykin, 2005) The network acquires "knowledge" by learning on the available data and stores it in the interneuron connections, so called weights (Haykin, 2005). An important aspect of neural networks is the ability to capture linear trends in the training data while resisting local perturbations (Goodfellow et al., 2016). Many studies investigating the implementation of ANN and Deep Learning (DL) frameworks in hydrological tasks have been conducted in recent years (Sit et al., 2020). Any neural network, regardless of architecture, is composed of neurons. The processes within a neuron are visualized in Fig. 1. The models are trained on daily timestep, with data containing both dry and rainy years to acquire best possible results in all conditions.

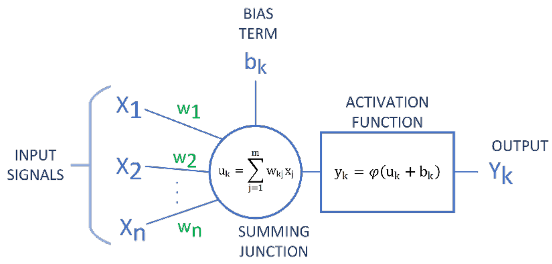

Fig. 1 Nonlinear model of a neuron (created according to: (Haykin, 2005))

Results

The preliminary model was trained on mean daily upstream runoff and daily precipitation (2008–2013), with validation and testing on independent data (2013. and 2014, respectively). According to Thapa et. al. (Thapa et al., 2020), Adamax optimizer and MSE loss function were selected. Figure 2. shows the last year of training, validation and testing runoff of the preliminary model. Given the promising results with only nine precipitation gauges and two upstream runoff gauges as inputs to the LSTM neural network, it is expected that a model with additional inputs in the form of mean air temperature, relative humidity, wind speed, and solar radiation and/or snow depth should perform as well, or possibly better.

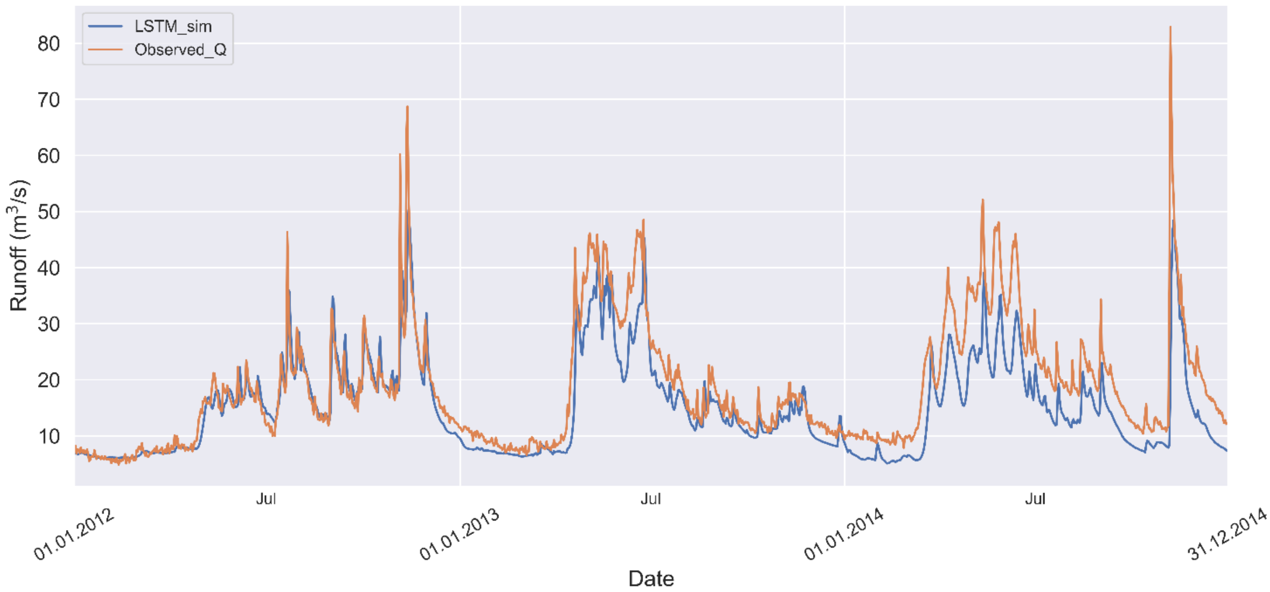

Fig. 2 Observed and calculated runoff – Drava, Lienz

It has to be taken into account that the test model was trained for only 30 epochs, without fine-tuning the hyperparameters (default learning rate=0.0015, two LSTM layers with 0.1 dropout). The model slightly underestimates the runoff, which is especially noticeable in the validation and testing period, during early summer snowmelt periods (May, June, July). It is expected that fine-tuning the model hyperparameters, increasing the training duration and providing additional input data (especially snow depth and air temperature) will improve the model performance.

Conclusion

The study presents an ANN based hydrological model implemented in a mountainous basin driven by snow and ice melt. The aim of the study is to present the predictive capabilities od data-driven models, even in complex terrain and geological conditions. In particular, with adding snow depth data, further improvements are expected compared to a model with only precipitation and upstream runoff as input data.

References

Arnold JG, Srinivasan R, Muttiah RS & Williams JR (1998) Large Area Hydrologic Modeling And Assessment Part I: Model Development, *Journal Of The American Water Resources Association*, **34** (1), 73–89

Duan Z, Liu J, Tuo Y, Chiogna G & Disse M (2016) Evaluation Of Eight High Spatial Resolution Gridded Precipitation Products In Adige Basin (Italy) At Multiple Temporal And Spatial Scales, *Science Of The Total Environment*, **573**, 1536–1553

Fontaine TA, Cruickshank TS, Arnold JG & Hotchkiss RH (2002) Development Of A Snowfall-Snowmelt Routine For Mountainous Terrain For The Soil Water Assessment Tool (SWAT), *Journal Of Hydrology*, **262** (1–4), 209–223

Goodfellow I, Bengio Y & Courville A (2016) Deep Learning, The Mit Press, 785 pp.

Haykin S (2005) Neural Networks - A Comprehensive Foundation, Mcmaster University, 823 pp.

Neitsch SL, Arnold JG, Kiniry JR & Williams JR (2011) Soil And Water Assessment Tool User's Manual Version 2005, Temple, Texas: Texas Water Resources Institute

Sit M, Demiray BZ, Xiang Z, Ewing GJ, Sermet Y & Demir I (2020) A Comprehensive Review Of Deep Learning Applications, Hydrology And Water Resources, *Water Science & Technology*, 2635–2670

Tekeli AE, Akyürek Z, Şorman AA, Şensoy A & Şorman AÜ (2005) Using Modis Snow Cover Maps In Modeling Snowmelt Runoff Process In The Eastern Part Of Turkey, *Remote Sensing Of Environment*, **97** (2) 216–230

Thapa S, Zhao Z, Li B, Lu L, Fu D, Shi X, Tang B & Qi H (2020) Snowmelt-Driven Streamflow Prediction Using Machine Learning Techniques (Lstm, Narx, Gpr, And Svr), *Water* **12** (6), 1734–1751

Tuo Y, Duan Z, Disse M & Chiogna G (2016) Evaluation Of Precipitation Input For Swat Modeling In Alpine Catchment: A Case Study In The Adige River Basin (Italy), *Science Of The Total Environment*, **573**, 66–82

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Neurohydrological experiments on the Danube

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Abstract

In this paper we give an overview of experiments with artificial neural networks on the Hungarian reach of the Danube River carried out by the Hungarian Hydrological Forecasting Service. Three areas were selected: rainfall-runoff modelling, water temperature simulation, and hydrodynamic model optimization. The statistical machine learning method is a universal interpolation and classification tool, but showed poor performance when applied for correlation in complex hydrological situations. Despite very strong learning skills of neural networks even a conceptual model gave more consistent and superior results through validation, and the statistic method is more sensitive to overlearning than deterministic methods. Promising results were achieved with artificial neural network based auto-calibration method built for a 1 dimensional hydrodynamic model as it is more of on interpolation type of task. The neural network successfully learnt the behavior and response of the model at different roughness scenarios and gave better and better estimations of the optimum set with each additional epoch.

Introduction

The machine learning type artificial intelligence approaches have a long history reaching back to the work of McCulloch & Pitts (1943). Rosenblatt (1957) presented the concept of a perceptron but it got great interest only after its rediscovery by Rumelhart et al. (1986). The nonlinearity of the multilayer perceptron (MLP) was a significant advantage compared to the linear behaviour of the Rosenblatt perceptron, and by the error propagation method it was possible to find the weights of the internal synapses. The first hydrological application of artificial neural network (ANN) was by Daniel (1991) but it was followed by a great number of studies and it is still an intensively studied area. Comprehensive reviews on neural hydrology (or neurohydrology) were made by Govindaraju (2000/a and 2000/b) and Tanty & Desmukh (2015), while numerous case studies are also available (Rabi et al. 2015, Temizyurek & Dadaşer-Çelik 2018, Zhu et al. 2018, Zhu et al. 2019).

Methodology

Rainfall-runoff modelling

The study area for rainfall-runoff modelling was the lower mountainous catchment of Galga River in Hungary. It is a small catchment where usual hydrological modeling does not provide satisfactory results. The applied rainfall-runoff model was of conceptual type developed and operated by the Hungarian Hydrological Forecasting Service. It is based on empirical formulas including the Horton formula and the Thornthwaite equations and discrete linear cascade modeling of the distributed runoff components. Calibrations were carried out on the data from 2015 to 2019, validation on 2013–2014 and 2020.

Water temperature simulation

The selected site for water temperature simulations was on the Danube River at Paks gauging station. Two methods were compared to the artificial neural network, a physically based energy balance estimation and a simplified conceptual model ignoring all the terms but the sensible heat with an added transfer coefficient. The data set for calibration was from summer 2015 to 2017, while the validation was done on data from summer 2017–2018, and summer 2018–2019 periods.

Hydrodynamic model optimization

One dimensional hydrodynamic models are often calibrated by automatic algorithms due to their fast calculation speed and manageable amount of calibration parameters. A possible application of an artificial neural network is to learn the response of such a 1D model during multiple simulations and taking the advantage of its outstanding regression capabilities to estimate a perfect set of calibration variables. The study site for this experiment was the entire Hungarian Danube reach, and the embedded 1D hydrodynamic model was developed and programmed by the Hungarian Hydrological Forecasting Service. The model is robust enough to be able to provide results at extreme roughness values, and is capable of high speed simulation for the high number of required learning data.

Calibration runs were done on the entire year of 2018 due to extreme low flow events and the entire year of 2019 due to high flow events.

Artificial neural networks

An artificial neural network (ANN) is considered as a black box model and by opening this box one does not find the representation of the physical processes, thus method extraction is not yet possible. It is an artificial architecture consisting of neurons and synapses resembling the biological cognition and its information processing characteristics. The feed forward multi-layer perceptron (MLP) stands of at least three layers of neurons: input, hidden and output layers. Classifications and regressions are two possible applications of ANNs. Speaking of either application some inputs are given at the input layer and outputs are received at the output layer. These outputs are compared to target values and based on the errors the ANN is able to learn (Rumelhart et al. 1986). This training method requires a great number of training data carefully selected to describe the general range of the resembled process because the extrapolation capabilities of an ANN are poor (Govindaraju 2000/b). We used the widely applied error back-propagation with added momentum for the training process.

Results

Rainfall-runoff modelling

The ANN based method provided superior results on the learning data, but showed poor performance during any validation attempts. The conceptual rainfall-runoff calculation showed consistent performance during both of the calibration and the validation runs.

Water Temperature Simulation

The estimation of the energy balance showed consistent performance in every situation always giving satisfactory results. The conceptual model performed slightly poorer and showed less consistency on the validation time series. The ANN reached the tightest fit during calibration even better than the physical model, but did not perform well in the validation scenarios.

Model optimization

The ANN based auto-calibration algorithm successfully trained itself on the results of the continuously running hydrodynamic model, giving better and better estimations on the set of roughness values for zero error. Finally the results were highly satisfactory and superior compared to manual trial-and-error optimization.

Conclusion

The main difference between the non-parametric statistic and deterministic methods is the consistency of the performance. While the ANN is able to achieve superior calibration results, it is easily overtought. ANN water temperature and rainfall-runoff models were good tools to analyze a set of data, but any step outside of the already introduced set of information leads to extrapolation which is a weakness of ANNs. Interpolation is a main power of ANNs so finding an optimum in a defined set of data is a promising task. The response of a hydrodynamic model is highly complex and non-linear, but the applied training method allowed the ANN to draw correlation between numerous roughness values and errors on the Hungarian Danube reach, and also to give better and better estimations of the optimum. Experiments in this area are still ongoing with the calibration of other rivers and also other HD models, e.g. HEC-RAS.

References

Daniel, T., M. (1991): Neural networks – application in hydrology and water resources engineering. Proc. Int. Hydrol. and Water Resour., Institution of Engineers, Perth, Australia.

Govindaraju, R. (2000/a): Artificial Neural Networks in hydrology. I: Preliminary concepts. *J. Hydrol. Eng.*. **5**/2. 115–123.

DOI:10.1061/(ASCE)1084-0699(2000)5:2(115)

Govindaraju, R. (2000/b): Artificial Neural Networks in hydrology. II: Hydrologic applications. *J. Hydrol. Eng.*. **5**/2. 124–137.

DOI: 10.1061/(ASCE)1084-0699(2000)5:2(124)

McCalloch, W., S. and Pitts, W. (1943): A logic calculus of the ideas immanent in nervous activity. *Bull. of Math. Biophys*., **5**, 115–133.

Rabi, A., Hadzima-Nyarko, M. and Sperac, M. (2015): Modelling river temperarure from air temperature: case of the River Drava (Croatia). *Hydrological Sciences Journal*. **60**/9:1490–1507.

https://doi.org/10.1080/02626667.2014.914215

Rosanblatt, F. (1957): The perceptron. A perceiving and recognizing automaton. Cornell Aeronautical Laboratory, Buffalo, New York.

Rumelhart, D., E., Hinton, G., E. and Williams, R., J. (1986): Learning internal representations by error propagation. Parallel distributed processing, MIT Press, *Cambridge*. **1**, 318–362.

Tanty, R. and Desmukh, T. (2015): Application of Artificial Neural Network in Hydrology- A Review. International Journal of Engineering Research and. 4/6.

DOI: 10.17577/IJERTV4IS060247.

Temizyurek, M. and Dadaşer-Çelik, F. (2018): Modelling the effects of meteorological parameters on water temperature using artificial neural networks. *Water Sci Technol*. **77**(5-6):1724–1733. doi: 10.2166/wst.2018.058.

Zhu, S., Nyarko, E., K., Hadzima-Nyarko, M. (2018): Modelling daily water temperature from air temperature for the Missouri River. PeerJ 6:e4894; http://doi.org/10.7717/peerj.4894

Zhu, S., Nyarko, E., K., Hadzima-Nyarko, M., Heddam, S., Wu, S. (2019): Assessing the performance of a suite of machine learning models for daily river water temperature prediction. PeerJ. 7:e7065

http://doi.org/10.7717/peerj.7065

Improvement of the operational HEC-HMS hydrological model embedded in the Flood Forecasting and Warning System of the Sava River Basin

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Introduction

The flood risk management (FRM) is a complex set of actions and measures that need timely implementation in order to be successful (protect people, infrastructure, cultural heritage and environment). The FRM in the transboundary river basins have additional specific needs and challenges. The Sava River Basin is shared by five countries (Slovenia, Croatia, Bosnia and Hercegovina, Serbia and Montenegro) and the objectives of transboundary FRM are regulated with the Framework Agreement on the Sava River Basin (FASRB) and the accompanying Protocol on Flood Protection to FASRB (Protocol). With respect to an efficient flood awareness, the Protocol has committed all Sava countries to establish a joint flood forecasting system for the entire Sava River Basin under the coordination of the Secretariat of the International Sava River Basin Commission (ISRBC).

The Flood Forecasting and Warning System in the Sava River Basin (Sava FFWS) was established in 2018 and represents a comprehensive and versatile system that combines data and models of individual countries, as well as common models, making it a unique example of cross-border cooperation in flood forecasting even globally. The Sava FFWS consists of five hosting locations: primary and three backup server modules are installed in national institutions in the four Sava countries, and archive and web server in the Secretariat of ISRBC. The platform integrates a system for collecting real-time hydrological and meteorological data from national networks, weather radar and satellite imagery from different sources, numerous weather prediction and hydrologic and hydraulic models as well as outputs of existing national forecasting systems.

Regarding hydrologic modelling, the backbone of the forecasting system represents the Sava HEC-HMS model, as the only hydrologic model that covers the entire Sava River Basin. The model was developed by the U.S. Army Corps of Engineers, in close collaboration with the Secretariat and national experts and initially calibrated as event-based model, and lower reliability was recognized during the continuous simulations in the operational period. Therefore, the Sava FFWS users decided to upgrade and improve the Sava HEC-HMS model. This challenging effort, led and coordinated by the Secretariat of the ISRBC, resulted with an improved Sava HEC-HMS model which is now more suitable for continuous hydrological simulations.

Methodology

The methodological approach consisted of these steps: (1) preparation of the necessary technical documentation and time plan for the work of national experts; (2) initial improvement of the model to account for the new hydrologic and meteorological stations; (3) collection of historical hydrological and meteorological hourly data for the period 2010–2018; (4) upload collected data to Sava HIS/Sava FFWS Archive module; (5) improve the model components; (6) calibrate and validate the new model setup; (7) perform hindcast analysis and validate operability performances of the model through the Sava FFWS testing module including comparison of different model versions.

The Sava River Basin of approximately 97.700 km^2 was represented through 235 subbasins which were initially selected to take the local hydrology into account. A unique local characteristic is the presence of karst, which affected the boundaries and parameterization of subbasins.

In the new HEC-HMS model 199 meteorological stations and 134 river gauging stations are available (from Sava HIS and Sava FFWS database), which is an increase of 125 meteorological and 41 hydrological stations compared

to the initial setting of the model. The calibration was performed at 107 calibration points, an increase of 32 points compared to the initial model. For all measuring locations, the data from the period 2010-2018 were successfully collected and uploaded to Sava HIS and Sava FFWS archive, which were later used for validation and hindcasting. In the calibration phase the Sava HEC-HMS model was forced with observed precipitation, observed temperature and long term monthly averaged evapotranspiration. The input data set was harmonized to an hourly time step. The precipitation data to the subbasins were transformed by using inverse distance method. The temperature data were transformed by using weighting factors and included altitude correction. The snow-water equivalent was derived from satellite-based information. The basin parameters for the model, such as soil losses, hydrograph transformation, baseflow and routing were derived from GIS layers and through the calibration process.
The 9-year period was divided into two subperiods where one was used for the calibration and the other for the validation. For the determination of the model parameters two approaches were used: trial-and-error method and the built-in automatic calibration procedure of HEC-HMS. The goodness of fit for each model parameter was evaluated based on the objective function i.e. NSE and RMSE. For both of them the hydrograph volume, peak discharge and peak timing were also monitored.

Results

The main improvements of the Sava HEC-HMS calibration process include: (1) improvements of the meteorological inputs with higher spatial and temporal data coverage for precipitation and air temperature; (2) some corrections of the meteorological model of snow melting; (3) increased number of calibration points; (4) increased number of calibrated sub-basins, up to 98 from initial 66; (5) longer time series of discharge observations; (6) new version of the Sava HEC-HMS model integrated under the Sava FFWS testing module. The model skill was evaluated using NSE on the period from 2010 to 2018 and about 50% of stations score a NSE greater than 0.55 (rates: good and very good), while a higher percentage of stations score a NSE greater than 0.40 (rate: satisfactory). The higher NSE scoring was achieved in the upstream parts of the basin and along the Sava river. The new model accuracy and NSE increased in comparison to the initial model.

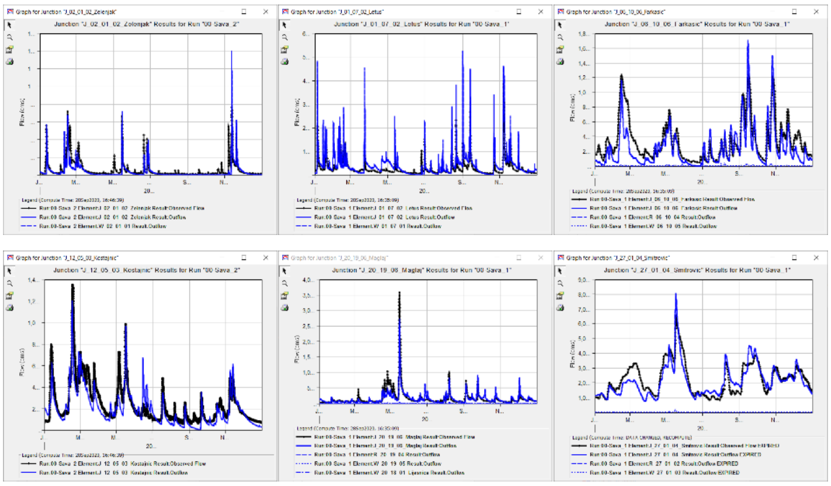

Fig. 1 Comparison of the simulation results (blue) and observed data (black)

Conclusion

The activities on improvement of the operational Sava HEC-HMS hydrologic model were performed in period January 2019 till June 2020. It was implemented by the national experts from the Sava FFWS users' organizations as a true joint action and coordinated by the Secretariat of the ISRBC. This paper presents the results of the Sava HEC-HMS model improvements and updated parameters, including a comparison of results of initial and improved models within the operational forecasting system. The hydrologic calculations were conducted for the period 2010-2018 including extreme May 2014 flood and several smaller floods, with evaluation of daily mean hydrologic conditions and processes. The main findings are as follows: (i) performance and forecast accuracy of the existing Sava HEC-HMS model was significantly improved; (ii) the model was (re)calibrated for both high flows (for accuracy) and low flows (for stability and model performance); (iii) data sources for further developments were improved; (iv) a solid background for an international team of experts was established.
Considering that the Sava FFWS users have access to all data and workflows as well as managing the functioning and further developments of the system, it was very important that the national experts were fully involved in the study. Therefore, joint work and close cooperation of the national experts (duty forecasters) should be emphasized

as an additional achievement, as follows: (i) experts deeply familiarized with the HEC-HMS software capabilities as well as with methods and techniques implemented into the Sava HEC-HMS model; (ii) upgraded own knowledge how to calibrate a such model; (iii) recognized all benefits of the model, its limitations and possible future applications; (iv) much more prepared for using this model under the Sava FFWS.

After performed activities and obtained results, the following recommendations are suggested: (i) development of a more complex soil loss method capable of long-term soil moisture accounting; (ii) a more detailed analysis of snowmelt within the model necessary (snow data availability); (iii) reservoir regulations at dams through the incorporation of a reservoir regulation model component (HEC-RESSIM). The future updates should utilize remote sensing data inputs for the soil moisture accounting, snow melting, reservoir regulating as well as other specific applications in the Sava HEC-HMS.

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References

International Sava River Basin Commission, ISRBC (2004) Framework Agreement on the Sava River Basin

International Sava River Basin Commission, ISRBC (2010) Protocol on Flood Protection to the Framework Agreement on the Sava River Basin

H. L. Zhang et al. (2013) The effect of watershed scale on HEC-HMS calibrated parameters, *Hydrology and Earth System Sciences*, **17**, 2735–2745

US Army Corps of Engineers, USACE (2000) Hydrologic Engineering Center, Hydrologic Modeling System HEC-HMS - Technical Reference Manual, 94–104

US Army Corps of Engineers, USACE (2020) Hydrologic Engineering Center, Hydrologic Modeling System HEC-HMS - Technical Reference Manual, web edition: HEC-HMS Technical Reference Manual (army.mil)

Ice monitoring and forecasting practices in the Danube River Basin

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Introduction

Within the framework of the DAREFFORT (Danube River Basin Enhanced Flood Forecasting Cooperation) project, an international initiative between the Danube River Basin countries came into being aiming to mitigate flood risk on the catchment level and support knowledge exchange and sharing of best practices within the Danube Basin (DAREFFORT, 2019). E-learnig materials were delivered for educational institutes, experts of national and regional authorities and non-professionals to facilitate the knowledge exchange. In the course of this activity an overview of the ice monitoring and forecasting practices in the Danube River Basin has been carried out. In this paper we'd like to present the findings of the acquired knowledge about the applied practices.

Methodology

Due to climate change, rising winter mean temperature and water temperature in Central Europe implied a considerable decrease in the number of ice cover days on the Danube river in the second half of the 20th century (Ionita et al., 2018). Beside the increase in the temperatures, the regulatory activities changed the ice regime of the Danube as well (ICPDR, 2018). However during a severe winter, when meteorological conditions favour ice formation, various forms of ice can evolve on our rivers. Monitoring and forecasting of ice phenomena is important, since in case of ice floods, ice reduces the water transport capacity of the given river section and damming increases the rate of the water level rise above the section. With an accurate forecast the risks of river ice related flooding could be reduced.

Table 1 Information on ice events reports (DAREFFORT, 2019)

Country	Ice events report	Information provided on ice events			
		Percentage of surface covered by ice	Thickness of ice cover	Duration of ice cover	Type of ice event
Austria (Lower Austria)	No				
Bosnia and Herzegovina	Yes	x			
Bulgaria	Yes				x
Croatia	Yes		x	x	
Czech Republic	No				
Germany	Yes			x	
Hungary	Yes	x	x	x	x
Moldova	Yes		x	x	x
Romania	Yes	x	x	x	
Serbia	Yes	x	x	x	
Slovakia	Yes	x	x		
Slovenia	No				
Ukraine	Yes	x	x	x	

In the Danube Basin national hydrological services are responsible for monitoring the ice cover along the main flow of the Danube River and its navigable tributaries. To retrieve information on the applied practices,

questionnaires were prepared during the implementation of the DAREFFORT project where, among other topics, information provided concerning ice events and availability of ice maps was also covered. Table 1 gives an overview on what kind of information on ice events is provided by the countries. It shows that almost all countries provide information on ice to some extent. Usually the percentages of surface covered by ice, the type of ice event, thickness of ice cover and duration of ice cover is granted by the consulted countries. Hungary is the only country where additionally an ice map is also provided.
In the course of the project, participating countries also carried out reports on their flood and ice forecasting methodologies. In four countries (Croatia, Hungary, Slovakia, Ukraine) more information was available on the applied methods, so river ice monitoring and forecasting practices are presented in more depth through the example of these countries.

Results

Among the four countries, which provided detailed overviews of the applied practices, Croatia, Hungary and Slovakia disseminate their results online to the public. In Croatia a possible ice warning, in Slovakia the ice phenomenon is available through the daily hydrological reports and in Hungary along with the current ice conditions the forecasts are also published.

Conclusion

Ice monitoring and forecasting in the Danube River Basin is an important issue not only because of waterborne transport but the damage caused by river ice related flooding as well. Almost all countries in the Danube basin give information on river ice events however ice reporting is various in light of what kind of information is provided.

Acknowledgements

We would like to thank the Croatian (Croatian Waters – Legal entity for water management) and Ukrainian (Ukrainian Hydrometeorological Center of the State Emergency Service of Ukraine) colleagues for their assistance with the collection of the information on their practices.

References

DAREFFORT (2019) http://www.interreg-danube.eu/approved-projects/dareffort

Ionita M, Badaluta CA, Scholz P, Chelcea S (2018) Vanishing river ice cover in the lower part of the Danube basin – signs of a changing climate, Scientific Reports, (2018) 8:7948, DOI: 10.1038/s41598-018-26357-w

Mladenović MB, Gombás K, Liška I, Balatonyi L (2018) Report on the ice event 2017 in the Danube river basin, ICPDR, 72 pp.

Proposal of flood risk assessment methodology in the study time period

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Úvod

Floods are a long-standing and still current problem not only in Central Europe, but all over the world. This natural event carries with it a certain risk, which can be avoided to a certain extent by appropriate preparedness, or at least partially mitigated its consequences. The most widespread method of determining flood risk worldwide is the creation of flood risk maps based on risk assessment using the generally applicable risk definition equation – risk = causality * consequence. Many foreign and domestic authors use hazard indices, vulnerability indices (Solín, 1998; V. David, 2008) as well as exposures (Mishra, Sinha, 2020) to calculate flood risk. Based on these three indices, a methodology for flood risk assessment is also proposed, which is described in this paper.

Methodology

Theoretical resources

The presented proposal of flood risk assessment methodology is based on the study of a multi-index model of flood risk assessment on the Yangtze River in China (Zhang et al., 2020). The authors in this study focused on the development of a multi-index conceptual model for the assessment of the Yangtze River in two parts – the first part deals with the preparation of the index system, the second is focused on the analysis of the proposed procedure in ArcGIS software. However, the presented paper describes the proposal of the flood risk assessment methodology based on the first part of the mentioned study, ie on the preparation and content of the index system.

The authors of the flood risk assessment study on the Yangtze River proposed a multi-index system consisting of three layers – an object layer, an index layer and an indicator layer. The object layer includes the rated Yangtze River, the index layer includes the hazard index, the vulnerability index and the exposure index. The last indicator layer contains 13 indicators that contribute to flood risk. The data contained in the indicator layer were collected and projected in a GIS environment, and subsequently, using the hierarchical AHP method, these data were assigned values according to the relative importance of each indicator. The final flood risk was calculated by the following equation:

$$YRBFR = H * w_H + V * w_V + E * w_E \qquad (1)$$

where *YRBFR* [-] represents the flood risk, *H* represents the hazard index, *V* represents the vulnerability index, *E* represents the exposure index and the w_H, w_V and w_E values are the weight values of said indices.

The index layer of this methodology includes the mentioned indices of gambling (threat), vulnerability and exposure. The content of these indices are indicators, which are divided as follows: the hazard index (threat) is assigned an indicator of the cumulative average of maximum precipitation for 3 days. The vulnerability index includes indicators: data on the absolute elevation between the designated point and the sea level, data on the relative elevation, data on runoff density depending on the density of the river network in the area, surface runoff and surface coverage factor, financial returns, financial savings, levels health services and monitoring and alert system data. The exposure indicator contains 4 elements – population density, GDP per capita, degree of soil erosion and risk of soil contamination.

From the point of view of data availability and variation, it is possible to apply the multi-index conceptual model to any field of application, and it is also possible to substitute different input profitable values into individual layers. The following chapters present a proposal and a collection of data that will be used to assess flood risk in accordance with the currently valid legislation of the Slovak Republic.

Results

Appropriate transformation of the mentioned methodology proposes a new way of flood risk assessment through available data taken from Reports on the course and consequences of floods in the Slovak Republic (Min ŽP SR), which will also serve as input data for flood damage assessment in the next part of processing.

However, the aim of this paper is to show the content of the indicator layer. The index layer is preserved, it contains the indices of danger, vulnerability and exposure. The following indicators are proposed for the threat indicators: cumulative amount of precipitation, number of declarations III. degree of flood activity, surface runoff. The vulnerability index includes indicators: the affected population, protected landscape areas and the condition of flood protection facilities. The last index of the exposure contains indicators: flooded buildings, flooded non-residential buildings, damaged civil engineering structures, number of damaged animals, other flood damage.
Based on the available data, the individual indicators will be assigned a point rating, which will then be multiplied by the weight of the individual indices. The indices have a total value of 100% with the following distribution: hazard index = 30%, vulnerability index 40% and exposure index 30%. Furthermore, these weights are divided between the indicators. In the next part of the elaboration of the proposed methodology, the content parts of individual indicators will be filled in, and the final values will be quantified.

Conclusion

The presented paper on the proposal of the flood risk assessment methodology is still in the stage of elaboration and topic, which will be gradually expanded and supplemented by the methodology of flood damage assessment based on the indicator layer in the previous methodology. Work is currently underway on a flood risk assessment methodology and a study of the available literature to plan for optimal results. The output of the proposed methodology will be the determination of flood risk from the monitored area for a certain period, flood risk maps, which may relate to the total risk, but also to the partial risks in connection with individual indices. Another planned output is the creation of a methodology for flood damage assessment, the input data of which will also be based on the data available in the Report on the course and consequences of floods in the Slovak Republic.

Acknowledgment

This work has been supported by the Slovak Research and Development Agency through the projects SK-PT-18-0008 and SL-PL-18-0033. This work has also been supported by the Ministry for Education of the Slovak Republic through project VEGA 1/0308/20 Mitigation of hydrological hazards – floods and droughts – by exploring extreme hydroclimatic phenomena in river basins.

Resources

David V. (2008) Metodika stanovení povodňového rizika v malých povodích. Sympozium GIS Ostrava 2008. Sborník z mezinárodního symposia konaného 27. – 30. 1. 2008 v Ostravě. VŠB Technická univerzita Ostava.

Ministerstvo životného prostredia Slovenskej republiky (dostupné 29.3.2021) Správa o priebehu a následkoch povodní na území Slovenskej Repuliky (online zdroj)

Mishra K, Sinha R. (2020) Flood risk assessment in the Kosi megafan using multi-criteria decision analysis: A hydro-geomorphic approach, In: *Geomorphology,* číslo **350**, 106861 (článok odborného časopisu)

Solín Ľ (1998) Hodnotenie povodňového rizika – súčasný stav výskumu, In: *Geologický časopis*, vol. **50**, no.1, pp 35–57 (article in a professional journal)

Šimák L. (2006) Manažment rizík, Žilinská univerzita v Žiline

Zhang D. et al. (2020) A GIS-based spatial multi-index model for flood risk assessment in the Yangtze River Basin, China, In: *Environmental Impaxt Assessment Review,* číslo **83**, 106397 (article in a professional journal)

Combining ground data from rain gauges and satellite data for the purpose of analyses and forecasts of floods and flash floods

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Introduction

The availability of detailed well distributed in spatial information on precipitation is of essential importance for the hydrological modeling and forecasting. The distribution of the ground stations is quite irregular and thus distances between stations could be quite big, sometimes more than 35 km. This information is not sufficient for correct spatial distribution of precipitation. On the other hand, precipitation has high variability in space, especially in convective events. One of the possibilities to achieve high density gridded precipitation is remote sensing techniques such as using radars, products derived from satellites, etc.
One of the aims HSAF project is to produce different products for precipitation, snow and soil moisture with high resolution in order to facilitate the hydrological modelling. Bulgaria, in particular NIMH, is a partner in HSAF project since 2009 and the obligations are to validate and hydrovalidate these products.
In this paper we show how we use a GAM-Kriging interpolation of rain gauges data and this technique will be applied in two different synoptic situations in Bulgaria in the periods 30 May – 05 June 2019 and 10 – 12 January 2021. The first one (from 2019) is characterized with convection scheme and the second one - with cloud scheme. In both situations in many places in Bulgaria there were floods and flash floods. Analyses and statistics will be made using data for both cases.

Methodology

In this study 3 hour sums from automatic and conventional stations are compared with HSAF's H05b product. The H05b is accumulated precipitation by merging MW images from operational sun-synchronous satellites and IR images from GEO satellites (i.e., product P-IN-SEVIRI) (hsaf.meteoam.it). Location of the conventional and automatic stations is shown on the fig. 1.

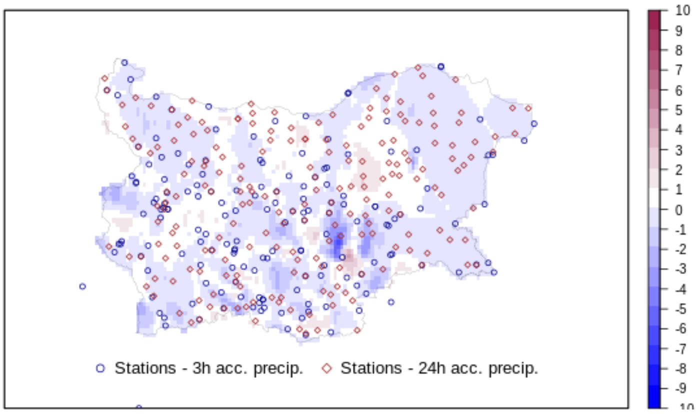

Fig. 1 Interpolated differences /Case II - Case III/ at 2019-06-02 18:00 and used meteorological stations

Kriging is one of the most widely used geostatistical method for spatial interpolation (Webster and Oliver, 2001) that predicts a value for a location with no data, based on the spatial autocorrelation of observed data. We used a kriging method Generalized additive model (GAM) with Ordinary Kriging (OK). OK is a standard kriging method based on the assumptions of stationary means and covariances (Webster and Oliver, 2001)(Hengl, 2009). On the other hand GAM is a semi-parametric extension of generalized linear models (GLM), where no parametric coefficients are estimated for predictors. GAM allows a nonlinear relationship between the response and explanatory variables.

We show three cases:
Case I – Precipitation data only form H-SAF H05B product – direct visualization of 3h accumulated precipitations with extracted values over the rain gauge locations;
Case II – 3h Accumulated Precipitation data only form Rain Gauges. Interpolation using GAM Regression Kriging. With GAM formula: RR ~ 1;
Case III – Mixed Precipitation data from Precipitation stations and H-SAF H05B, Interpolation by GAM Regression Kriging GAM formula: RR ~ H05B.RR.0, where H05B.RR.0 is the spatial data, where each pixel is divided by the maximum precipitation from the satellite grid at the time of interpolation. We use this method to add more weight to the in-situ observations.

Results

In points with measured 3h precipitation data, the coefficient of determination (Nash, 1970) are shown in table 1.

Table 1 NSE coefficient

		2019	2021
Case I	Measured precipitation vs H05B values	0.212	0.187
Case II	Measured precipitation vs Measured Interpolated values	0.978	0.989
Case III	Measured precipitation vs Mixed Interpolated values	0.977	0.989

According to values of NSE and PBIAS (Moriasi et al., 2015) introduces the following criteria for assessing the accuracy of model data: NSE > 0.80 and PBIAS ≤ ± 5 the results are very good. In particular at 2019-06-02 18:00 h GMT the statistics between interpolated precipitation data /measured/ and mixed interpolation with H05B data are: PBIS = 3.9 and NSE = 0.973 (Fig. 1).
For result verifications we used 24h accumulated precipitation from 204 conventional stations in Bulgaria. According to (Moriasi et. Al, 2015) values of NSE = 0.651, PBIAS=-16.9 and R^2=0.685 show satisfactory results. On Fig.2 are shown scatter plots of 24 hours sums for case I and case III.

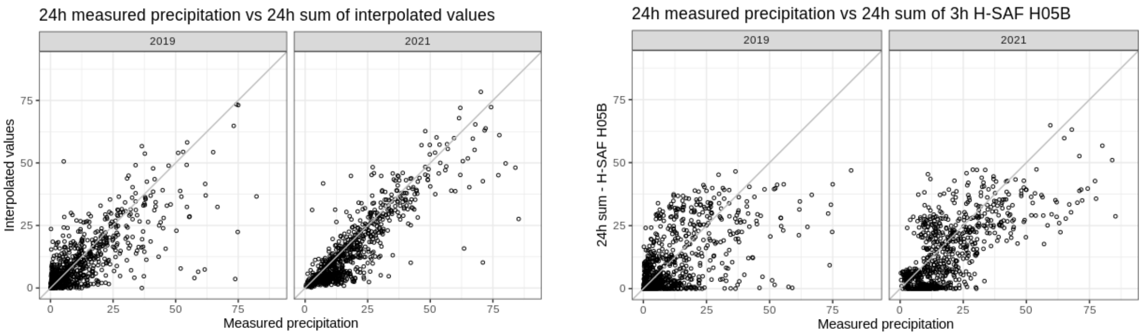

Fig. 2 Scatter plots of 24 hours sums for case III (left) and case I (right)

Conclusions

The spatial data for precipitation from satellite product H05B can be used to improve GAM – Kriging interpolation of three hour precipitation data from rain gauges. This improves the spatial distribution of precipitation and statistical parameters NSE, PBIAS and R^2. Still the H05B product cannot be used alone in places with no meteorological stations for now-casting of flash floods or for identification of the quantity of the precipitation in case of floods and flash floods.

References

Hengl T. (2009) A practical guide to geostatistical mapping.

http://hsaf.meteoam.it/Products/ProductsList?type=precipitation

Nash JE; Sutcliffe JV (1970) River flow forecasting through conceptual models part I - A discussion of principles, *Journal of Hydrology*. **10** (3), 282–290.

Moriasi DN, Gitau MW, Pai N, Daggupati P. (2015) Hydrologic and Water Quality Models: *Performance Measures and Evaluation Criteria* // Trans. ASABE. **58** (6), 1763–1785.

Webster R, Oliver MA (2001) Geostatistics for environmental scientists. Statistics in practice series Chichester: Wiley.

A semi-automatic method for flood wave separation

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Introduction

In the last decades, the question of possible changes in the hydrological regime of rivers in the form of increasing extremeness of flood discharges due to climate change is a relatively discussed topic. Therefore, one of the hot topics of water management today is to assess the validity of flood characteristics used to design or assess various water structures, including water reservoirs. Today, with both observed and simulated discharges available for relatively long periods and with our better understanding of flood generating mechanisms in catchments, it is a good opportunity to verify current methods, assess their uncertainties and develop new methodologies to estimate design flood characteristics.

This study presents a part of the methodology that has recently been developed to construct realistic design flood hydrographs for flood risk map creation and dam safety reassessment. The methodology is based on a multivariate statistical analysis of flood wave characteristics derived from real flood hydrographs identified from a time series of river discharges. Since in practice, it is the identification of flood hydrographs that is very often associated with large uncertainties, we present a new semi-automatic approach for flood wave separation.

Methodology

Method for semi-automatic flood wave separation

Different tasks in hydrology and water management emphasise certain aspects of flood wave characteristics. As a result of this the analysis of flood wave characteristics is often carried out for various seasons with different types of flood generating mechanisms involved. Because of this, the methodology proposed expects the user to select the flood waves used in the analysis by providing the position of their peaks in the time series of river discharges. The method itself is used to identify the beginning and the end of the flood wave hydrographs. To do so, a set of rules has been defined to decide whether a particular time step is either the beginning or the end of the wave. The behaviour of the method can be adjusted by a set of parameters that enable the method to escape local minimums or to include flood waves with more than one peak. The method relies heavily on the approximation of base flow, which can be carried out using one of the five methods included.

Tool for semi-automatic flood wave separation

In the case of more complex flood waves, it is often challenging to say where it begins and where it ends. This is especially true for winter flood waves with long duration and several peaks caused by short, low-intensity rainfall events. Because of this, it is important to perform a visual assessment of the separated flood waves and, if needed, manually adjust the position of its beginning or end. In order to do so, a new tool has been developed to set up the parameters of the separation algorithm and to visually check and adjust the separated flood waves (see Fig. 1). This tool was created in MATLAB and deployed as a standalone desktop application. Its main functions are: baseflow separation, semi-automatic flood wave identification, calculation of flood wave characteristics, estimation of a representative shape of flood wave hydrographs, creation of design flood hydrograph.

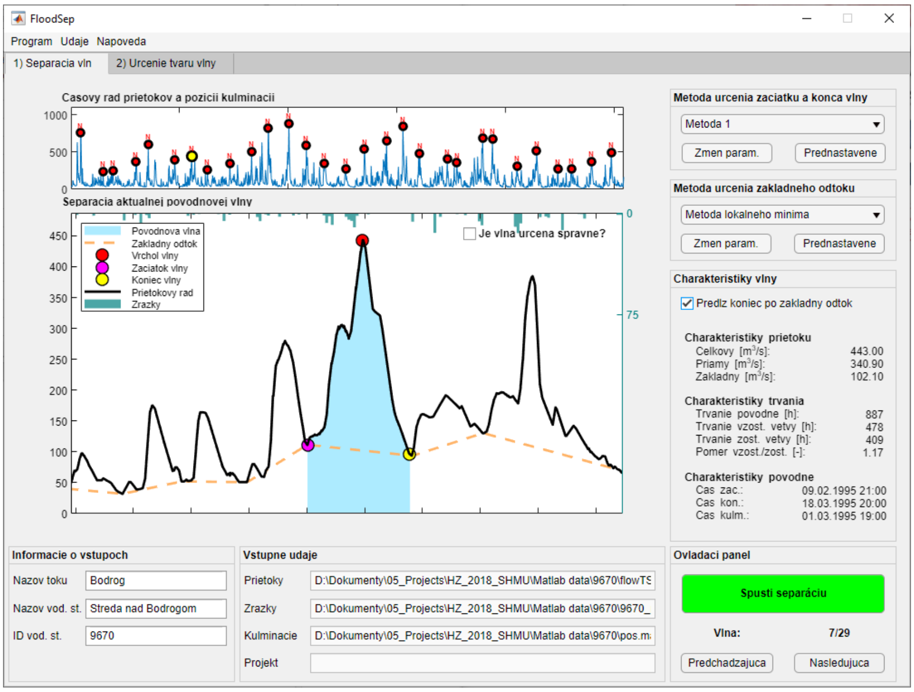

Fig. 1. *The graphical user interface of a tool for the semi-automatic separation of flood wave hydrographs.*

Results

The new tool has already been tested on a number of catchments in Slovakia for which design flood hydrographs were estimated. The semi-automatic approach of the method enabled to easily separate the selected flood waves from which a shape of a representative hydrograph could also be estimated (see Fig. 2).

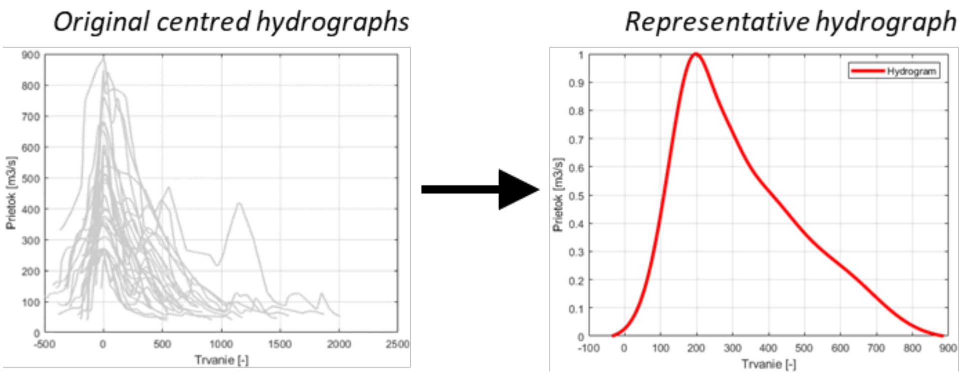

Fig. 2. *Example of the separated flood waves and the resulting shape of the representative flood hydrograph.*

Conclusion

The analysis of flood wave hydrographs plays an important role in the estimation of design flood hydrographs. To do so, one must be able to reliably separate flood hydrographs from a time series of river discharges. The large variability and complexity of flood generating mechanisms do not allow to develop a single separation method that would be suitable in all conditions. Therefore, a simple and flexible semi-automatic method has been developed to separate flood wave hydrographs in an easy to use tool with a user interface. The tool has already been tested in practice and proved to work well in a large number of different hydrological conditions in Slovakia.

Acknowledgements

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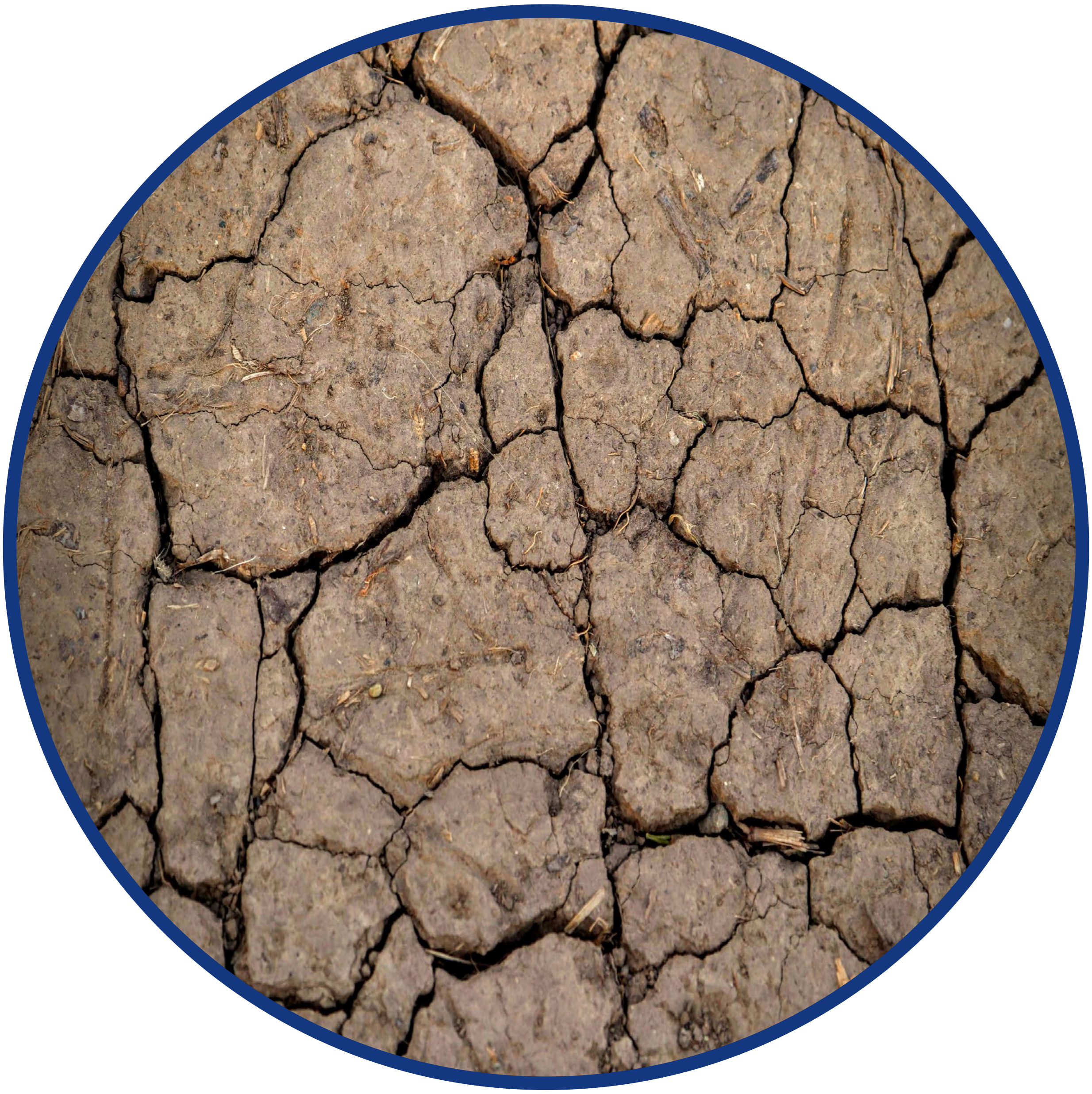
Topic 4

Learning about hydrological extremes: then, now & in the future



Impact of the flood from 2010 on the groundwater level in the Rye Island

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Introduction

In the beginning of June 2010, almost 50-year flood discharge (culmination on June 7) was achieved in Komárno on the Danube River, which contributed to the increase in water levels in the lower part of the Váh River. The culmination in Kolárovo took place in the night of June 6-7 at a level corresponding to the 3rd degree of flood activity. The Váh River in Kolárovo and the Danube River in Komárno culminated at about the same time (Blahová et al., 2010).

In the area of the lower part of the Rye Island (Slovakia), a gradual rise in the groundwater level has been recorded since the beginning of the hydrological year 2010, with a maximum groundwater level at the beginning of June. The reason was, on one hand, the exceptionally high precipitation totals recorded in May and June, as well as the high-water inflow from the Nitra River and the Little Danube River and high water levels on the Danube River (SHMI, 2010). In some groundwater level observation boreholes, the maximum measured groundwater levels were exceeded in 2010, while in others the measured heads approached the maximum levels observed for the entire observation period (SHMI, 2020).

Methodology

The studied part of the Rye Island, Slovakia, is the area in which preliminary assessment of flood risk (Červeňanská et al., 2016; Červeňanská et al., 2020) evaluates the possibility for a negative phenomenon caused by rising groundwater levels or even a potentially significant flood risk. It is a lowland area, which is protected by dykes against direct flooding, with relatively small depths of groundwater level below the ground. However, dykes do not exclude the possibility of bank filtration into the subsoil in the adjacent area, which often causes its waterlogging, even flooding by groundwater. Therefore, a system of drainage channels and pumping stations was built to adjust the regime of internal waters and groundwater (Duba, 1968; Porubský, 1976).

The impact of the flood situation from the 2010 on the groundwater level in the Rye Island was solved using the MODFLOW numerical model in the Groundwater Modeling System (GMS) environment (Aquaveo, 2020). A modeling protocol, which was used for creation of the numerical model, is described in (Anderson, Woessner, 1992).

The calibrated steady state model capturing the relatively steady state situation before the flood in 2010 served as an initial condition for the unsteady model simulating the period from April 2010 to February 2011.

Results

Figure 1 shows the contours of the calculated piezometric groundwater head for June 7, 2010 during the flood wave culmination of the Danube River in Komárno and the culmination of the Váh River in Kolárovo at the same time. As it can be seen in this figure, a large part of the area was either waterlogged, in the extreme case even flooded due to rising groundwater level. Figure 1 also illustrates the depth of the calculated groundwater level under the terrain. In addition to flooded areas (with a negative value of the depth), it is also possible to see areas where the depth to groundwater table is less than 0.80 m below ground surface. The value 0.80 was not selected randomly; it represents the average depth of freezing in Slovakia (STN 73 1001: 2010). It is therefore the depth in which the foundations of non-basement buildings are located.

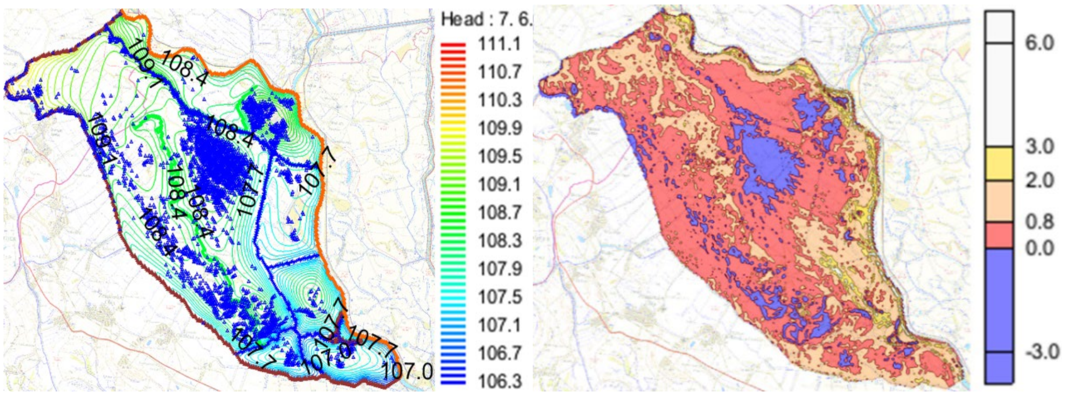

Fig. 1 Map of calculated piezometric head (on the left) and map showing the depth of the groundwater level (area: 215 km^2)

Conclusion

The article presents results of the research concentrating on the groundwater flooding phenomena in the lower part of the Rye Island, especially on the consequences of the flood situation from 2010 on the groundwater level in the studied locality.

The contours of the calculated piezometric groundwater head for June, 7 2010 during the culminations of the flood waves on the Váh River and on the Danube River was illustrated defining a large flooded part of the area of interest due to rising groundwater level. This can have a lot of negative impacts, e. g. for the agricultural production, or even flooding of sewage treatment plants and contamination of drinking water in wells. Also, the map showing the depth of the groundwater level under the terrain was constructed.

The research establishes the basis for a construction of the flood hazard maps and flood risk management plans taking groundwater into account, which was in the background compared to the fluvial flooding.

Acknowledgements

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References

Anderson MP, Woessner W (1992) Applied Groundwater Modeling. Simulation of Flow and Advective Transport. California, 381 pp.

Aquaveo (2020) Groundwater Modeling System. [Online]. Available: https://www.aquaveo.com/software/gms-groundwater-modeling-system-introduction. Accessed 2 May 2020.

Blahová A, Matoková K, Smrtník P, Hazlinger M, Masár T, Bírová M, Parditka P, Pecho J, Lešková D, Poórová J, Jarošová M, Kozub J, Škoda P, Mráček P, Wendlová V (2010) Flood situation on the streams of western Slovakia in May and June 2010 (in Slovak), Bratislava, 197 pp.

Červeňanská M, Baroková D, Šoltész A, Janík A (2016) Preliminary assessment of flood risk due to increased groundwater levels in Slovakia, in 16th International Multidisciplinary Scientific GeoConference, Albena, Bulgaria, 30 June - 6 July 2016, 223–228.

Červeňanská M, Baroková D, Šoltész A (2020) Case study on groundwater flooding: the lower part of the Rye Island, *Journal of Landscape Management*, vol. **11**, no. 1, 7–11.

Duba D (1968) Groundwater hydrology (in Slovak), Bratislava, 352 pp.

Mcdonald MG, Harbaugh AW (1988) A Modular Three-Dimensional Finite-Difference Ground-Water Flow Model. Chapter A1. Washington, 588 pp.

Porubský A (1976) Water management plan of the Slovak Socialist Republic. VII. Danube basin. Map no. 5. Water management-hydrogeological map 1: 200 000. Text explanations (in Slovak), Bratislava 150 pp.

Slovak Hydrometeorological Institute (2010) Assessment of the hydrological year 2010 (in Slovak) [Online]. Available: http://www.shmu.sk/File/Hydrologia/Monitoring_PV_PzV/Monitoring_kvantity_PzV/KnPzV_2010/KnPzV_2010_hodnotenie.pdf. Accessed 7 January 2020.

Slovak Hydrometeorological Institute (2020) Data provided from the Slovak Hydrometeorological Institute.

STN 73 1001: 2010, Geotechnical structures. Foundation of buildings (in Slovak). Office for Standardization, Metrology and Testing of the Slovak Republic, Department of Technical Standardization.

Application of an indicator system for integrated space-time analysis and drought management in Northwestern Bulgaria

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Introduction

Extreme floods and droughts have become more frequent in recent years. The river basin management planning process is the mechanism through which the available water resources and demand are balanced, thus avoiding water scarcity and drought. Adequate measures have to be included in the Programme of Measures when and where it is needed, a specific Water Scarcity and Drought Management Plan should be developed. Specific indicators need to be selected and defined to identify "prolonged droughts" to prevent and mitigate its effects.
Hydrological drought and low flow depend on the meteorological conditions, but the severity of drought's impact depends on the vulnerability of water supply systems (WSS) and measures. Reduction of natural resources ("hydrological drought") in water sources is associated with the reduction in available water resources for water supply including regulating runoff ("water scarcity" or so called "operational" and "socio – economic" drought). Reduced water availability exerts a negative impact on people, environment and economic sectors. The severity of the "prolonged drought" is related to its duration, specificities of the river basin, reservoir management and impact. Specific indicators need to be selected and defined to identify "prolonged droughts" to prevent and mitigate its effects (Ortega-Gomes T. 2018).

Methodology

To this end a methodological approach for integrated spatial-temporal analysis of drought, low flow and water scarcity is applied. The methodology consists five stages: assessment of climate factors and meteorological drought identification; assessment of water resources and hydrologic drought identification; simulation modeling (simulation model SIMYL), water balances - operational and socio-economic drought assessment; water scarcity and "prolonged droughts" identification; mitigation measures and Drought Management Plans.
The Indicator system (including reservoirs levels and inflow, some impact indicators – environmental and socio – economic) and drought indices (such as Standardized Status Index) have been developed in National Institute of Meteorology and Hydrology (NIMH) for drought early warning and drought management needs (Table 1.)

***Table 1.** Proposed Indicator system for drought early warning and drought management*

Drought type	Evaluation Indices and Indicators	Experimentally applied
1.Meteorological Drought	**Rainfall** - SPI	SPI 1, SPI 3, SPI 6, SPI 9, SPI 12, SPI 24
2.Agrometeorological Drought	**Soil moisture -** SMI	n.a.
3.Hydrological Drought	**Runoff -** SRI	SRI 1, SRI 3, SRI 6, SRI 9, SRI 12, SRI 24
4.Hydrogeological Drought	Groundwater levels, Base Flow Index	Wells levels, springs flow, BFI
5. Operational and Socio-economic Drought and water scarcity	**Reservoir inflow** Tributaries threshold levels	Monthly and annual reservoir inflows with certain probability of exceedance - 50%, 75%, 95%. Threshold levels.
6. Operational and Socio-economic Drought and water scarcity	**Reservoir levels** Operational Indices and Dispatch Schedules. State Index. Percent from effective capacity.	***State Index (SI) and Standardised State Index (SSI)*** for reservoir and river catchments
7. Operational и Socio-economic Drought and water scarcity	Water shortages in drought conditions. Indicators for assessing socio-economic and environmental impact.	Water supply reliability index. Environmental runoff vulnerability. Defining reservoir significance criteria.

As indicators for the reservoirs inflow are suggested the developed by NIMH for the Ministry of Environment and Water monthly and annually inflows with certain exceedance probability (50%, 75%, 95%) Table 2.

Table 2. Monthly and annual inflows with certain exceedance probability PE (50%, 75%, 95%)

Reservoir	PE %	Monthly reservoir inflow with certain probability of exceedance, 10^6 m^3												
		I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	S
Ogosta	50%	16,71	20,31	35,35	49,62	45,96	26,42	11,74	7,35	6,68	7,86	10,68	17,22	255,91
	75%	11,21	11,91	15,04	28,87	23,31	11,57	7,24	5,08	3,42	4,74	6,4	9,19	137,97
	95%	0,76	0,13	0,29	0,83	2,42	0,08	0,97	0,34	0,01	0,26	0,18	0,05	6,29
Srechensk a Bara	50%	2,01	5,68	3,08	8,02	9,27	7,44	4,09	2,06	1,14	1,84	2,46	2,35	49,43
	75%	1,7	2,53	2,26	6,27	6,89	4,66	2,61	1,23	0,7	1,28	1,47	1,51	33,11
	95%	0,66	0,71	1,26	2,85	2,84	2,09	1,15	0,72	0,41	0,5	0,44	0,47	14,09

The derived Standardised State Index is calculated as a weighted sum. The weight of the reservoirs take into account their significance for the water supply and river basins, the deficiency during drought and the impact to society, ecology and economy. For this purpose the developed in NIMH for MOEW „Criteria for determination of reservoir from Appendix №1 of the Water Low as complex and significant" are applied.

Results

The used approach is on three levels: in the valleys of Northwestern Bulgaria, Ogosta river Basin and Water Supply System "Ogosta"– "Srechenska bara" Reservoir. A special feature of the area is the transfer of water through water intakes, dams and collecting derivations from transboundary of Nishava river basin to Ogosta river (cascade "Petrokhan") and from one sub-basin to another. Fig.1 and Fig.2.

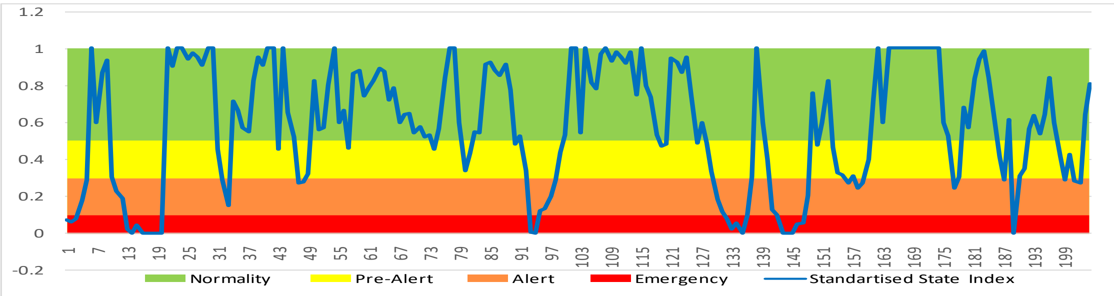

Fig. 1. Standardised Status Index - Srechenska Bara Reservoir (2001-2015)

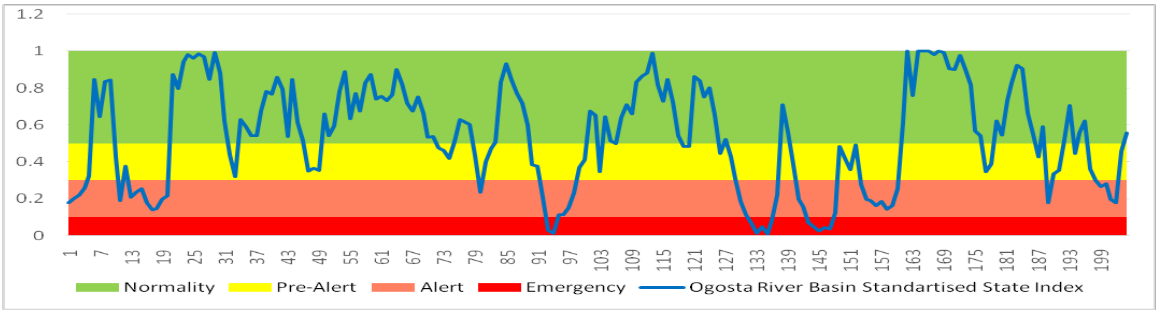

Fig. 2. The composite Standardised Status Index - Ogosta River Basin (2001-2015)

Conclusion

The application of these approaches as part of the Early Warning and Decision Support System are presented. The study of the minimum runoff shows a deepening of negative trends, which is another prerequisite for increasing the vulnerability of river waters to drought. For "prolonged" droughts, we have a good match of reservoir state indices with SRI24. The results, obtained from the experimental application for the specific river basins and water management systems, can be applied in practice for the purposes of the MOEW.

References

Ortega-Gomes T, Pérez-Martín MA., Estrela T (2018) Improvement of the drought indicators system in the Jucar River Basin, Spain, *Science of the Total Environment*, **1**, 276–290

Pluvial floods in Tulcea municipality

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Introduction

The municipality of Tulcea is located on a promontory of the north-Dobrogean slope, being delimited to the north by the Danube, to the east by Colnicul Hora, to the west by Lake Somova and to the south by a line that coincides with the torrent valleys that go to the Danube on the south-north direction (Fig.1).

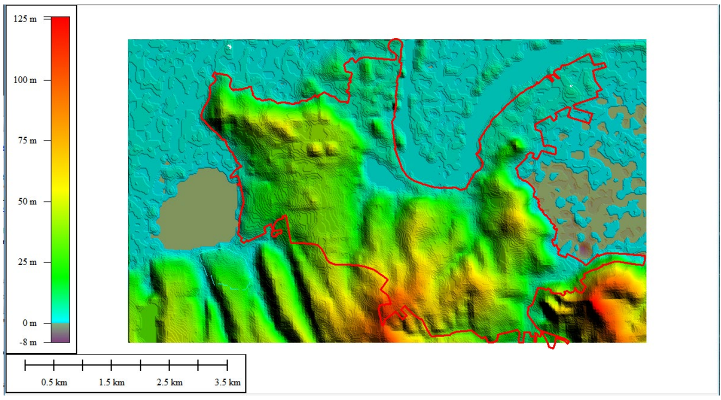

Fig. 1 Administrative limits of Tulcea municipality and the DEM.

The floods generated by torrential rains occur in the meadow area, which is characterized by a lower slope than the slope of the surrounding hills. The meteoric water is directed quickly to the low areas of the city, where due to ground topography and existing infrastructure (flood protection dikes along the Danube) the water velocity tends to zero and stagnates at the surface of the land. In order to have an overview, the problematic areas were marked in Fig.2.

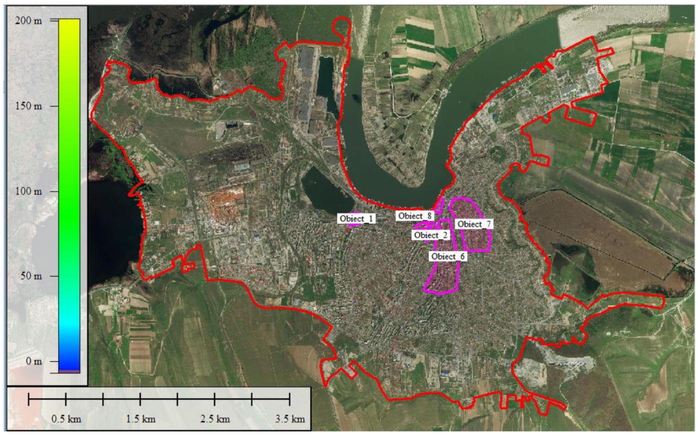

Fig.2 Administrative limits of Tulcea municipality and the DEM.

Methodology

To build the hydrological models for the Tulcea municipality most of the data processing activities were performed using GIS tools based on digital terrain model, orthophotos, administrative boundary of Tulcea municipality, delineation of currently flooded areas and the rain network. The urban catchments of the corresponding sewage systems were generated. The hydrological models were built using the software package MIKE by DHI. An event modeling approach was used, opting for the UHM-MIKE11 hydrological module. For the calculation of the net

precipitation 2 loss models, namely: Proportional Loss (leakage coefficient) and SCS Loss model (SCS Method) were used. The SCS dimensionless hydrograph model was used for the transfer function.
For the calibration of the parameters, the event between 12.09.13 10:00 and 13.09.13 8:20 was analysed. The total duration is of approx. 22.3 hours, with maximum precipitation values recorded around 7:10 on 13.09.2013 (at the end of the event) and the amount of precipitation for this period is 67.8 mm. Precipitation before the maximum affects the initial humidity on the studied area, leading to an increase in the runoff coefficient. If the discharge capacity of the sewage collectors is exceeded, the excess water is accumulated at the ground surface. Because rainwater discharges from the sewer system are not measured, the calibration was performed indirectly, using the extension of the flooded areas, according to the different photos taken during the event. Based on local topography, 4 capacity curves (level-volume relations) corresponding to the depression areas were determined. First the water level in depression areas was approximated and then the corresponding accumulated volume was estimated. The calibration, which is affected by a certain degree of uncertainty, was considered good when the computed volume was close to the estimated volume of the depression areas. The validation was performed for 14.06.2016 event, having 25.6 rain depth, but which also flooded the center part of the municipality.

Results

As an example, only the results for central area are presented in the following. Due to the catchment morphology in this area, water is also accumulated from neighboring basins. The surfaces that generate an additional flow in this case are shown in Fig. 3.17. The maximum discharge simulated for 2013 event was 20.3m^3/s, while the accumulated volume in depression areas is 33,662m^3. The simulations, both for the recorded events and for the design rain corresponding to frequencies 1:2; 1:5; 1:10; 1:100, were performed in two hypotheses: a) sewage system fully functional; b) sewage system partially functional.

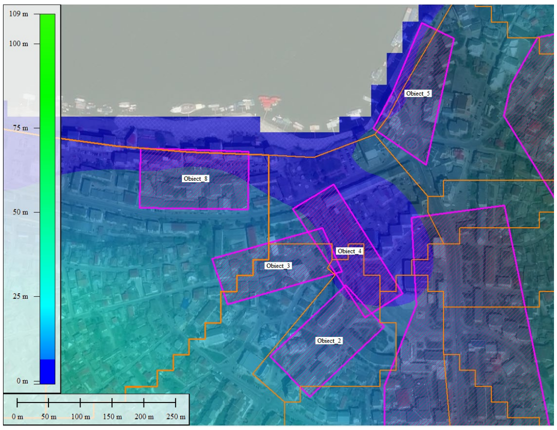

Fig. 3 The flooded areas derived for 2013 event.

Conclusion

The torrential rain floods in Tulcea municipality are due to a combination of factors: torrential rainfall, city topography (sudden transition from a high slope to a lower slope), street configuration, poor design and maintenance of sewer pipes (angles of 90 degrees along the sewage system, under evaluation of design capacity). Solutions for improving the present situations were provided. They consist in underground reservoirs in the lower part of the municipality to temporarily retain the excess rain and gradually releasing it into the Danube using the existing high-capacity pumping stations.

Low flow change analysis on the Tysa River within Ukraine

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Abstract

Indicators of Hydrologic Alteration method (IHA) for investigate of low flow characteristics and their changes along the Tysa River within Ukraine was used. The research was carried out based on the observations of 4 gauge stations that are located along the Tysa River. The mean daily discharges from the beginning of observations until 2018 inclusive was used. It turned out that at the Tysa River - Vylok Village gauge station the low flow trends differ from the trends at other gauging stations that are located in the upper part of the Tysa River.

Introduction

Knowledge of low flow trends is important for practice, especially for design, construction and operation of hydraulic structures on rivers, as well as for shipping, agriculture, etc. Extreme low flows, just like floods are causing a significant material damage. It should also be borne in mind that many scientists predict that in the warmer climate the droughts will become more common in the future. Longer periods of low flow and a decrease its discharge values, and for some rivers their complete disappearance will expect (Wimmer et al., 2015; Chang et al., 2017; Loboda et al., 2016).

The research of low flow is an actual task for the Tysa River, which is characterized by low flow twice a year, namely in winter and summer-autumn. In the dry years that have been observed in the last few years, there are some problems with water supply to consumers in the region.

Usually, the assessment of trends and changes in river flow is caried out on the basis of statistical approaches that allow to determine some quantitative indicators. Indicators of Hydrologic Alteration method is one of the most common of these approaches (Richter et al., 1997; Zhou et al., 2020).

The purpose of this research is to use the Indicators of Hydrologic Alteration approach to investigate of low flow characteristics and their changes along the Tysa River within Ukraine.

Methodology

The research was carried out based on observations of 4 gauge stations that are located along the Tysa River (Table 1). In the upper Tysa River the low flow analyze was carried out by the observation series at the rivers Chorna Tysa and Bila Tysa.

Table 1 List of the gauge stations on the Tysa River

№	Name of gauge station	Distance from the mouth, km	Catchment area, km^2	Latitude	Longitude	Altitude, m.a.s.l.	Daily data, years	Q_a, m^3 s^{-1}
1	Bila Tysa River – Luhy Village	15*	189	48º 04′ N	24º 56′ E	652	1955-2018	5.13
2	Chorna Tysa River – Yasynay Village	28*	194	48º 16′ N	24º 21′ E	650	1956-2018	4.78
3	Tysa River – Rakhiv town	962	1070	48º 03′ N	24º 12′ E	430	1947-2018	25.4
4	Tysa River – Vylok Village	808	9140	48º 06′ N	22º 50′ E	117	1954-2018	202

Note: * - to the confluence of the rivers Chorna Tysa and Bila Tysa; Q_a – multi-annual mean discharge.

The mean daily discharges from the beginning of observations until 2018 inclusive was used. The river flow at each gauge station was divided into five components: "Extreme low flows", "Low flows", "High-flow pulses", "Small floods", "Large floods", according to the method described by The Nature Conservancy (2009). This made it possible to separate from the total flow the extreme low flow, for which the IHA statistics were calculated.

The study calculated the following statistics: discharge thresholds for 5 flow components, [m^3 s^{-1}]; mean values of the extreme low discharges (peaks) during for each year, [m^3 s^{-1}]; mean duration of the extreme low flows, [days];

mean frequency of the extreme low flows, [number of cases/year]; mean Julian dates of the extreme low discharges (peaks) during for each year, [days].
Changes of low flow characteristics along the river and over time were also analyzed.

Results

The discharge thresholds are presented in Table 2. On their basis the river flows distribution into five components were carried out. Gauge stations along the Tysa River the multi-annual mean and discharge thresholds for 5 flow components in the direction from the origin to the mouth of the river are increasing (Table 1, 2, Fig. 1 a), that fully correspond to the physical and geographical conditions its formation.

Table 2 Discharge thresholds in the gauge stations along the Tysa River, [$m^3 s^{-1}$]

№	Name of gauge station	Large floods	Small floods	High-flow pulses	Low flows	Extreme low flows
1	Bila Tysa River – Luhy Village	39.5	24.2	6.43	3.68	1.54
2	Chorna Tysa River – Yasynay Village	58.2	32.8	5.96	3.19	1.15
3	Tysa River – Rakhiv town	351	174	31.3	17.4	7.0
s4	Tysa River – Vylok Village	2480	1370	244	133	56

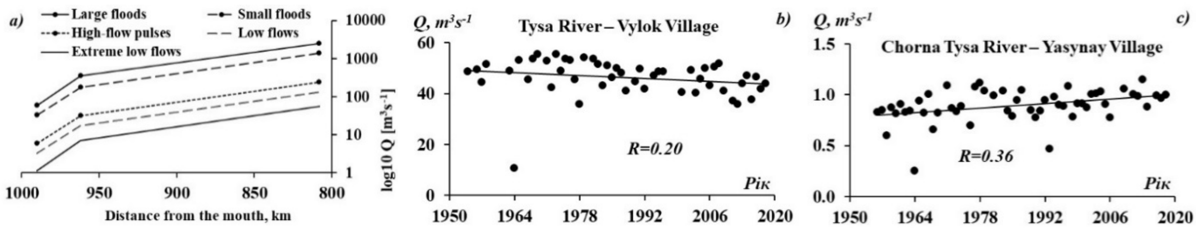

Fig. 1. *Discharge thresholds (a), mean values of the extreme low discharges (peaks) during for each year (b, c) at gauge stations along the Tysa River, [$m^3 s^{-1}$]*

The mean duration of extreme low flow is in the range of 9 to 14 days. According to the mean Julian dates, the extreme low flow peaks are observed in January in the upper part of the Tysa River and in October for the Tysa River - Vylok Village gauge station. Extreme low flow is observed in mean 4 times a year. The Tysa River - Vylok Village gauge station has the trends of extreme low flow which differ from the trends at other gauging stations that are located in the upper part of the Tysa River (Fig. 1 *b, c*).

Conclusion

The application of the IHA method for the study of low flow allow to gain a new knowledge and expand the understanding about its statistical indicators. At the same time, some features of the extreme low runoff of the Tysa River were founded. It is clear that the explanation of such trends in extreme low runoff requires further research with additional observation data as along the riverbed and its main tributaries.

References

Chang, J., Zhang, H., Wang, Y. & Zhang, L. (2017). Impact of climate change on runoff and uncertainty analysis. Natural Hazards, 88, 1113–1131. DOI: 10.1007/s11069-017-2909-0

Loboda, N.S., Bozhok, Y.V. (2016). Water resources of Ukraine in the XXI century under climate change scenarios (RCP4. 5 AND RCP8. 5). *Ukrainian hydrometeorological journal*, **17**, 114–122. DOI: 10.1007/s11069-017-2909-0 https://doi.org/10.31481/uhmj.17.2016.13

Richter, B. Baumgartner, J., Wigington, R., Braun, D., (1997). How Much Water Does a River Need? Freshwater Biology, 37(1), 231-249. https://doi.org/10.1046/j.1365-2427.1997.00153.x

The Nature Conservancy Indicators of Hydrologic Alteration (2009). Version 7. User's Manual, 75 p. https://www.conservationgateway.org/Documents/IHAV7.pdf

Wimmer, F., Audsley, E., Malsy, M., Savin, C., Dunford, R., Harrison, Rüdi P. A., Schaldach, R. & Flörke, M. (2015). Modelling the effects of cross-sectoral water allocation schemes in Europe. *Climatic Change*, **128**, 229–244. DOI: 10.1007/s10584-014-1161-9

Zhou, X., Huang, X., Zhao, H. and Ma, K. (2020). Development of a revised method for indicators of hydrologic alteration for analyzing the cumulative impacts of cascading reservoirs on flow regime. *Hydrol. Earth Syst. Sci*., **24**, 4091–4107. https://doi.org/10.5194/hess-24-4091-2020

Analysis of Low-Flow Extremes on the German Danube

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Introduction

Like all major rivers in Central Europe, the Danube in the German section (reference gauge Hofkirchen) has been affected by striking low-flow events in recent years, in particular in 2015 and still more in 2018. Hence, several questions about the hydrological evaluation of such events arose also with regard to the Danube river: which magnitude may low-flow events reach? How frequent do they occur? And did low-flow characteristics change during the last decades? Answers to these questions are of great socio-economic and ecological importance, e.g. regarding navigability of the federal waterway Danube or its hydro-ecological state. In addition to the focus on the Danube river itself, statements on possible hydrological conditions in the river basin are of interest, e.g. with regard to remaining groundwater supply during dry weather periods.

Methodology

Statistical and hydrological analyses of long-term series of suitable low-flow indices can contribute to the aimed statements. For this purpose, various hydrological methods are applied, including time series analysis, statistical inference and, in particular, extreme value statistics taking into account hydrologically meaningful information expansions. In this context, it has to be emphasized that low-flow events or years may show quite diverse characteristics. In addition to minimum flow values, the duration and deficit volumes below relevant threshold values of flow rate or water levels in the river (Danube), among others, are of interest.

In past decades, scientific methods in this context have been further developed and documented in literature. In order to facilitate access for practitioners to suitable methods, the working group HW-3.1 "Low Flow" of the German Association Water Management, Sewage and Waste (DWA 2021) brought them together, prepared and tested them for practical applications, and documented them in a new guideline for low-flow statistics (currently under review). Many of these methods have already been used in a Germany-wide study by the Federal Institute of Hydrology (BfG 2021) to analyse the low-flow sequence from 2015 to 2018. In present contribution, the Danube-related contents of this study (among others for gauge Hofkirchen) and thus also the methods mentioned above will be presented. However, compared to the guideline some methodical expansions and hydrological interpretations in specific relation to the Danube are added in order to reduce uncertainties.

First, meaningful low-flow indices are defined and extracted from daily hydrographs as annual series (water balance year from April 1 until March 31). Besides AM7 (annual minimum of 7-day average flow rate), annual indices of total and of maximum uninterrupted low-flow durations, sumD and maxD, as well as corresponding deficit volumes sumV and maxV are included. Durations and deficit volumes are related to graded as well as to practice-oriented or cross-gauge comparable threshold values of flow rate, e.g. to the mean annual minimum flow rate (MAM). Information about the temporal structure of these series may be derived using suitable graphical and statistical methods (among others, time series analysis, statistical inference, empirical probability plots). Focusing on low-flow indices of interest, they eventually allow the identification of complex hydrological developments, changes and interrelationships in large river basins and long-term periods, also beyond those to be identified by previously conducted analyses of daily flow series. These analyses may thus also contribute to the identification of a representative period for further analyses, e.g. extreme value statistics.

For extreme value statistics, theoretical cumulative distribution functions (cdf's) are selected and fitted to above mentioned series of the representative period. In the case of censored series of durations and deficit volumes, this is done within the framework of a conditional probability approach. However, in a straightforward application of these approaches, high uncertainty may arise in the range of extremes, especially if fitted cdf's are extrapolated beyond the observed range. To support the selection of reliable cdf's, information expansions with reference series (from the beginning of systematic observation, as well as with graded thresholds for duration and deficit volume) and hydrological interpretations are hence used.

Results

Time series analyses for the Danube gauge Hofkirchen revealed a long-term varying serial correlation in the AM7 series (lag = 1 year), which indicates a predominantly climate-induced variability on the low-flow related system memory of the Danube. Stationarity analyses of AM7 variance and of mean values of all above mentioned indices showed indications of an also climate-induced decadal variability, but no indications of significant long-term trends for the past decades. According to these analyses (in above mentioned BfG study also for other German river basins), a representative period of the water balance years 1961–2018 was selected, since it adequately represents both, the low-flow related current state of the river basins (with regard to anthropogenic influences) as well as the occurred extreme events (including those at the beginning of the 1960s). Furthermore, the series are sufficiently long so that serial correlation only has a weak effect on the process variance. Altogether, prerequisites for (classical) extreme value statistics are sufficiently fulfilled.
Selected and fitted cdf's were used to calculate statistical return intervals of the low-flow indices that occurred in the water balance years from 2015 until 2018 (and to compare them among river basins in mentioned BfG study). At the Danube gauge Hofkirchen, return intervals obtained for the 2015 indices are between 5 and 10 years (AM7) and between 10 and 20 years (sumD(<MAM) and sumV(<MAM)). Indices for 2018 are more extreme, with return intervals between 20 and 50 years where, in this year too, duration and deficit volume (>30 years) are more extreme than AM7. See Fig. 1 for further details, also with regard to the years 2016 and 2017 (for sumV(<MAM), obtained return intervals are similar to those for sumD(<MAM) in Fig. 1).

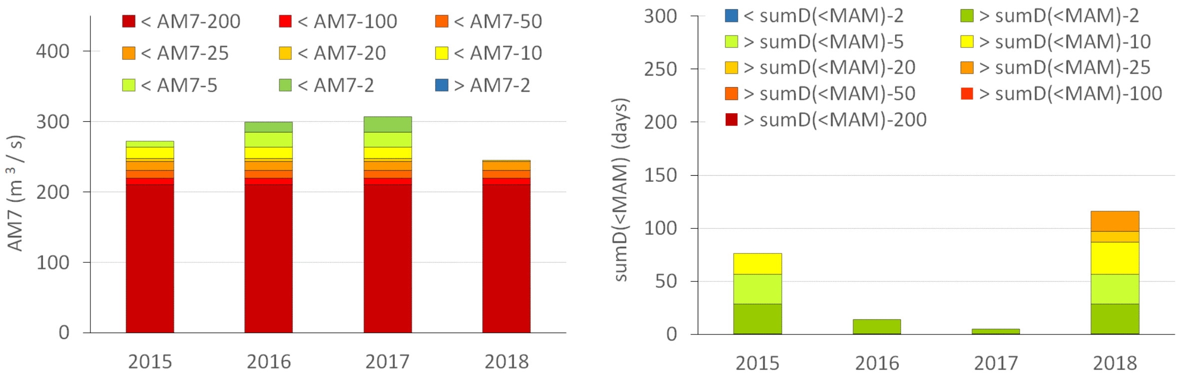

Fig. 1 Low-flow indices AM7 and sumD(<MAM) of the water balance years from 2015 until 2018 at the Danube gauge Hofkirchen in comparison with quantile classes of their long-term distribution in the series 1961–2018. The quantile classes are delimited by quantiles with selected return intervals T (in years), e.g. by AM7-T.

Conclusion and perspective

With these results, first low-flow statistics including the low-flow sequence from 2015 until 2018 as well as corresponding classifications of these years regarding their occurrence probability are provided for the upper Danube river (upstream of the Inn confluence). The results may serve as a starting point for the development of corresponding low-flow statistics for the entire Danube river and be further developed in the course of this. The spatial expansion and the occurrence of future extreme events may lead to further hydrological challenges (among others, non-stationary extreme value statistics, differentiated treatment of different low-flow types by event classification, analysis of simulated future projections in the context of statistics derived from past observations). With regard to this, above-mentioned publications of BfG and DWA provide further results and technical information that could be taken up and further developed in an interdisciplinary and international cooperation in the Danube basin in order to serve as a basis for a river basin related low-flow management. A first step on this way is the common project "Low Flows and Hydrological Drought in the Danube Basin" within the IHP-cooperation of the Danube countries under the project lead of CHMI.

References

BfG – Bundesanstalt für Gewässerkunde (2021): Die Niedrigwassersequenz der Jahre 2015 bis 2018 in Deutschland. BfG-Mitteilung Nr. 35. Koblenz.

DWA – Deutsche Vereinigung für Wasserwirtschaft, Abwasser und Abfall e.V. (2021): Merkblatt DWA-M 541 – Statistische Analyse von Niedrigwasserkenngrößen. DWA. Hennef.

SWICCA data in climate change impact study on 100-year floods

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Introduction

Climate change raises a number of issues and uncertainties that are the subject of studies and discussions. Reliable information on the potential change of future hydrological conditions in the field of water management is the basis for long-term strategies and adaptation planning.

The way one could determine the direction of change in flows is to analyse the trend from measured time series, especially in recent decades, as shown in Bertola et al. (2020). Although such analyses are necessary and important, their disadvantage may be the absence of sufficiently long series of observed data needed for analyses of flood flows with long return periods. Also, from these analyses it is not possible to predict the development of the climate in the future, which seems to be greatly influenced by the development of anthropogenic activity. Estimating the impact of climate change on flood flows based on projected climate change (climate projections) has several advantages. The advantage is that the analyzes consider climate change in the future and provide long series of observations of about 90–100 years. The disadvantage is the uncertainty of the estimate of socio-economic development, which is expressed in emission scenarios. Both of above mentioned methods are important, irreplaceable and complementary.

This work provides an analysis of the modelled expected change in 100-year floods (Q_{100}) for 11 Slovak river water gauging stations due to predicted climate change. It also analyses the possibilities of using data from the climate projections of global and regional climate models from the EURO-CORDEX initiative, as well as outputs from two hydrological models from the SWICCA database within the Copernicus service, for regional conditions in Slovakia. The SWICCA portal (Service for Water Indicators in Climate Change Adaptation, http://swicca.climate.copernicus.eu/, as of 15.5.2019) is the result of the work of the Swedish Meteorological and Hydrological Institute (SMHI) and was operational under the auspices of Copernicus until 2020. The portal will be replaced by a newer version in the Copernicus Climate Data Store (CDS), which is currently under development. The methodology of estimating Q_{100} based on the outputs of climate and hydrological models from the SWICCA database was for the first time used in Slovakia in the project C3S_441_Lot1_SMHI. Local case study "Flood warnings in a changing climate" were published in Gaál et al. (2017) for the Bratislava (Danube) water gauging station. Therefore, our goal was to test the database and methodology for more river basins in Slovakia, results of which are provided in this paper.

Methodology

For the purpose of this impact study, two types of time series of average daily flows were downloaded from the SWICCA portal (http://swicca.climate.copernicus.eu/, as of 01.02.2019) as outputs of eleven mutual combinations of five global circulation models (GCM), four regional climate models (RCM), three climate scenarios (RCPs 2.6, 4.5, 8.5) and two hydrological models HYPE and LISFLOOD. To estimate Q_{100}, frequency analysis was applied to the annual maxima of each member of the hydrological model output ensemble. The distribution of generalized extreme values (GEV) was used, while in case the data showed a significant trend, the non-stationarity of the environment was also taken into account.

The following procedure was chosen for estimating Q_{100}:
a/ download time series of average daily flows from all available climatic outputs and from two hydrological models HYPE and LISFLOOD from the SWICCA portal for selected gauges in Slovakia, b/ data check and bias-correction for the reference period 1971–2000, c/ selection of annual maxima, d/ conversion of annual maxima of average daily flows into annual peak, e/ trend analysis by non-parametric Mann-Kendall test, f/ frequency analysis (stationary or non-stationary).

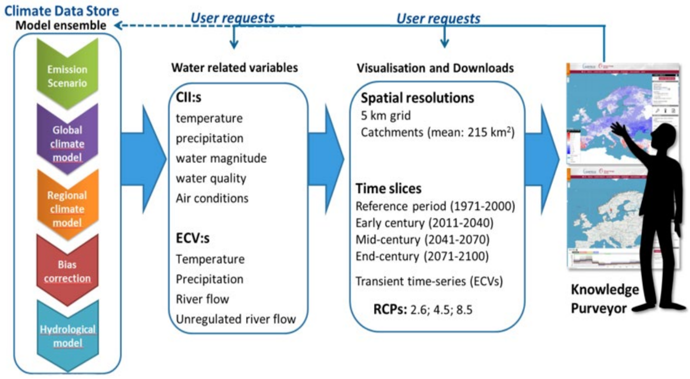

Fig. 1 Workflow to produce the climate impact indicators in co-design with the users in water management. Source: https://climate.copernicus.eu/operational-service-water-sector

Results

The results of the work can be summarized in several points as follows:

- Seven stations indicated increase, three stations decrease and one station without substantial change of Q_{100} for period 2011–2100,
- The largest river basins in the analysis (Danube to the Bratislava water gauging station and Moravia to the Moravský Sv. Ján) provided results that fell into the group with the least degree of uncertainty in terms of climate change impact on Q_{100} and had the most consistent results from the two hydrological models used,
- Higher estimation uncertainty for the three stations resulted from non-consistent outputs of the HYPE and LISFLOOD hydrological models. Here it may be appropriate to consider the use of a larger ensemble of hydrological models, similar like it is commonly done for climate models,
- The impact of climate change on the smallest river basins could not be satisfactorily estimated on the basis of hydrological outputs from the models of the SWICCA database, probably due to the rough spatial resolution of the models with respect to the size of the river basins. The impact of climate change for these river basins was modeled by a calibrated HBV model using climate inputs from the SWICCA database,
- The results of the climate impact on Q_{100} cannot be interpreted by only one average value for a specific water gauging station. Each value must be presented together with the quantified uncertainty of its estimation.

Conclusion

This work offers one of the possible ways to estimate the expected impact of climate change on flood flows based on available data from climate projections and hydrological models. The work points out to the usability of outputs from hydrological models of the SWICCA database, as well as to the uncertainties related to these outputs. The results of the work can contribute to the scientific discussion about the usability of regional climate projections not only from the SWICCA database, but also from other available databases and their way of application in impact studies in the field of water management.

Acknowledgements

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References

Bertola, M., et al. (2020): Flood trends in Europe: are changes in small and big floods different? *Hydrology and Earth System Sciences*, **24**, 1806–1822.

Gaál, L., Lešková, D., Kopáčiková, E. (2017): Changes in the 100-year flood at the Danube River in Bratislava due to the expected climate change. *Acta Hydrologica Slovaca*, **18** (2), 154–164 (in Slovak with English abstract and summary).

Hakala, K. et al. (2019): Hydrological modeling of Climate Change Impacts. Encyclopedia of Water: Science, Technology, and Society, Maurice, P. A. (ed.), Wiley & Sons, DOI: 10.1002/9781119300762.wsts0062

Spatial analysis of precipitation distribution that formed floods on the rivers of the Prut and Siret basins (within Ukraine) in June 2020

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Introduction.

The region of river runoff formation in the Prut and Siret basins is part of a potentially flood-hazardous area of Ukraine, where regular rain and snow melts-rain floods are recorded, some of which become catastrophic and are accompanied by negative consequences. The probability of flooding on the rivers of the basin increases with the fall of 20 mm of precipitation per day, and with the fall of more than 100 mm floods are becoming catastrophic (Kosteniuk, 2009). As a result of heavy and extreme torrential rains on June 20-25, 2020, a high rain flash flood was formed on the rivers of the Prut and Siret basins against the background of high water levels.

Methodology.

The study uses a geospatial analysis approach: geo-visualization, network analysis and surface analysis.

Results.

The weather situation on June 20–25, 2020 was associated with a series of sedentary cold atmospheric fronts, which were pressed to the Carpathians by eastern flows and due to convection and the formation of a single-center high-altitude cyclone (with very slow filling), caused very heavy and prolonged rains that caused the formation of several waves of high floods on rivers with catastrophic consequences. Very similar conditions were in the formation of high floods on the Carpathian rivers in July 2008, where the main cause of heavy, very heavy and prolonged rains on July 22–27, 2008, was a sedentary high-altitude cyclone over the Balkans and atmospheric fronts, whose activity intensified convection and orography (Kulbida et all, 2009).

Precipitation for 6 days – June 20–25, 2020 fell daily, heavy, violent and prolonged rains were observed, but especially intense rains were observed on June 22–23, when the amount of precipitation reached the criteria of natural disasters. The highest amount of precipitation per rain was recorded by meteorological stations in Chernivtsi and Ivano-Frankivsk regions:

- June 21 at the meteorological station Seliatyn (Chernivtsi region, Siret basin) heavy rain 43 mm in 10 hours;
- June 23 at the meteorological station Yaremche (Ivano-Frankivsk region, Prut basin) violent rain 106 mm in 12 hours;
- June 24 at the meteorological station Pozhezhevskaya (Ivano-Frankivsk region, Prut basin) heavy rain, 33 mm in 4 hours.

The amount of precipitation for June 20–25 at meteorological stations within the formation of runoff of the Prut basin in Ivano-Frankivsk region exceeded the climatic monthly norm of June by 1.1-1.6 times (Table 1).

Table 1. Characteristics of precipitation (mm), which formed a flood in June 2020, according to meteorological stations within the catchment area of the Prut and Siret rivers

Meteorological station	The June norm	The amount of precipitation for 20-25.06	Percentage to the June norm
Pozhezhevska	185	192	104
Yaremche	150	242	161
Kolomyia	106	124	117
Seliatyn	140	127	91
Chernivtsi	105	68	65

According to the measurement of precipitation at meteorological stations and hydrological posts within the Prut and Siret basins, a map of the distribution of total precipitation for the period 20–25 June 2020 was constructed, which formed an intense flood runoff (Figure 1).

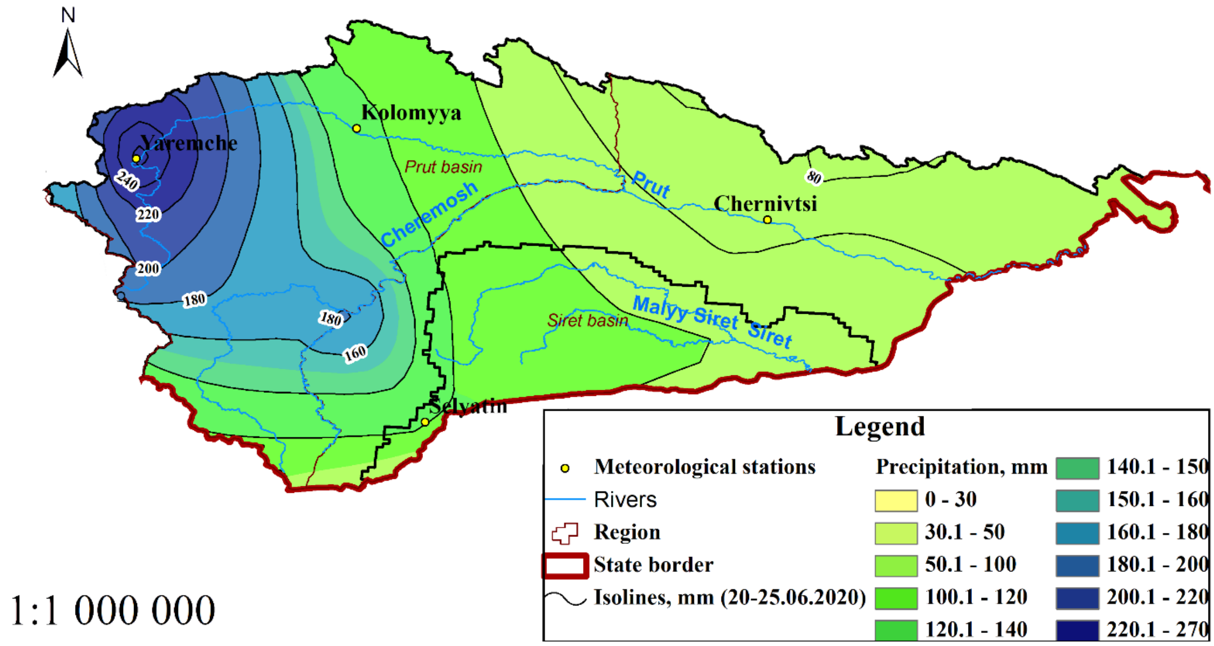

Figure 1. Total precipitation for June 20-25, 2020 according to meteorological stations and hydrological posts within the Prut and Siret basins (within Ukraine)

Analyzing the map (Figure 1), the maximum values of the total precipitation for June 20–25, 2020 were observed in the upper reaches of the Prut river (Vorokhta – Yaremche section), where the total precipitation was 200–240 mm, which is 1.6 monthly norm. In the upper reaches of the Bilyi Cheremosh and Chornyi Cheremosh rivers and at their confluence, the total rainfall was 150–190 mm. On the Prut river near the Kolomyia meteorological station, on the Cheremosh river near the Kuty hydrological post and in the basin of the Siret river, precipitation was distributed in the range of 90–130 mm. In the Prut area near Chernivtsi, the total rainfall was 56 mm.

Conclusion

A significant amount of precipitation on the rivers of the Prut and Siret basins caused the formation of two waves of rain flood: on June 20–22 and on June 23–25, which was formed against the background of the decline of the first wave. The second wave was more intense at the maximum values of rising water levels on the Prut river. Maximum water levels during the flood at many hydrological stations were higher than in 2010 and close to the catastrophic flood of 2008, and on the Iltsia river the maximum level exceeded the historical maximum. According to operational calculations, the repeatability of maximum levels and flow of rainwater in the area of the hydrological post Chernivtsi on the Prut river was – 10%. As a result of the flood, significant damage was inflicted on settlements and infrastructure in Chernivtsi and Ivano-Frankivsk regions.

Acknowledgements

It is dedicated to the memory of Victoria BOYKO, who connected her life with hydrology and played an important role in the hydrometeorological service and science of Ukraine.

References

Kulbida M., Boyko V., Petrenko L., Savchenko L. (2009). The analysis of time and spatial distribution of the precipitations which have generated floods on the rivers of Carpathian Mountains in July, 2008, *Hydrologist, hydrochemistry and hydroecologist.*, Issue **16**, pp. 92–98

Kosteniuk L. (2009). The catastrophic floods in a pool of the river Prut, Scientific notes [Vinnytsia State Pedagogical University named after Mykhailo Kotsyubynsky]. Series: *Geography*, Vip. **19**. - P. 43–49.

Rainfall thresholds related to pluvial flooding in urban areas – case study in the city of Zagreb, Croatia

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Introduction

Climate change is reflected, among other things, in intensification of the hydrological cycle and changes in precipitation extremes (Jha et al., 2012). This results in more frequent and intense pluvial urban flooding in cities around the world causing great material damage, including Croatia (Potočki et al., 2018, Jelić et al., 2020). Flash floods can occur anywhere, with low-lying areas with poor drainage being particularly vulnerable to waterlogging, and this is characteristic of many urban areas. The shorter the duration, the greater the likelihood of waterlogging disasters (Ma et al., 2020). Urban flooding cannot be prevented, but its harmful consequences can be significantly mitigated by effective preventive and operational measures. The development and improvement of forecasting and early warning systems as part of the risk management of natural hazards is considered one of the most effective ways to mitigate the impact of flash floods in cities (Zanchetta and Coulibaly, 2020). The most common approach is to compare the latest precipitation forecasts from numerical weather predictions with reference thresholds, often derived by statistical analysis of long-term records of point measurements (Alfieri et al., 2012). Thresholds for rainfall intensity and duration are developed for the occurrence of debris flows, landslides and floods (Cannon et al., 2008, Guzzetti et al., 2008, Diakakis, 2012, Papagiannaki et al., 2015).

Research on the temporal and spatial characteristics of short-term heavy rainfall events in Croatia has not been systematically conducted (Jurković et al., 2019). The RAINMAN project was focused on the development of practical new tools and innovative methods to reduce losses caused by heavy rainfall in the natural and built environment, and it presented preliminary evaluation of urban flood hazard in the city of Zagreb (RAINMAN project, 2019). Certain attempts to determine thresholds of critical precipitation in relation to the occurrence of floods in the city of Zagreb were made by Hrastovski (2016) analyzing only precipitation durations that exceeded 24 hours, so that shorter precipitation durations that trigger urban flooding should be investigated. Thresholds for rainfall intensity and durations up to 24 hours were derived for the city of Zagreb, specifically for Maksimir sub-area, and their performance for urban floods warning is evaluated.

Methodology

The methodology for determining critical rainfall threshold is based on comparing and linking flood impact indicators with flood hazard parameters. Flood impact parameters are made by analysis of precipitation data from the meteorological station Maksimir, obtained from the Croatian Meteorological and Hydrological Service. Data about flood hazard indicators are reports about interventions related to pumping water during urban flash floods collected by public fire brigades and civil protection services. In the analyzed period from 2007 to 2017, 989 interventions were recorded throughout the whole city of Zagreb. Detailed analysis was conducted for sub-area within a radius of 4,2 km around the meteorological station (selected as a smaller part of the watershed), 331 interventions were documented (Fig. 1). Out of 764 rainfall events, hourly precipitation data was analyzed, and the maximum of accumulated rain was calculated for durations of 1, 2, 3, 6, 12 and 24 hours. Rainfall events were separated into groups of related and non-related with flood indicators. Rainfall intensity-duration thresholds for the occurrence of pluvial floods were determined by plotting peak rainfall intensities of various time intervals vs. their respective durations for two groups of rainfall events. Two approaches were explored to determine a rainfall threshold that strongly indicated flood risk. The first was an empirical approach applied by Papagiannaki et al. (2015) defined by lowest rainfall intensities that pose no risk of flood events and by highest rainfall intensities which did not cause flood hazards. The second approach is based on statistical analysis of the data, examining 25th and 75th percentiles of the precipitation data as the lower and upper thresholds, respectively. The performance of both approaches is analyzed by determining the overall correctness, hit rate, and false alarm rate of presented rainfall thresholds is calculated (Eq. 1-3):

$$Hit\ rate = \frac{h}{m+h}, \quad (1)$$

$$False\ alarm\ rate = \frac{f}{c+f}\ , \quad (2)$$

$$Overall\ correctness = \frac{h+c}{h+m+f+c}. \quad (3)$$

where: h – number of interventions above threshold line [-], m – number of interventions bellow threshold line [-], f – rainfall events (without intervention) above threshold line [-] and c – rainfall events (without intervention) bellow threshold line [-]. To obtain the best overall correctness, the hit rate should be kept as high as possible while simultaneously, the false alarm rate should be kept as low as possible (Jang, 2015).

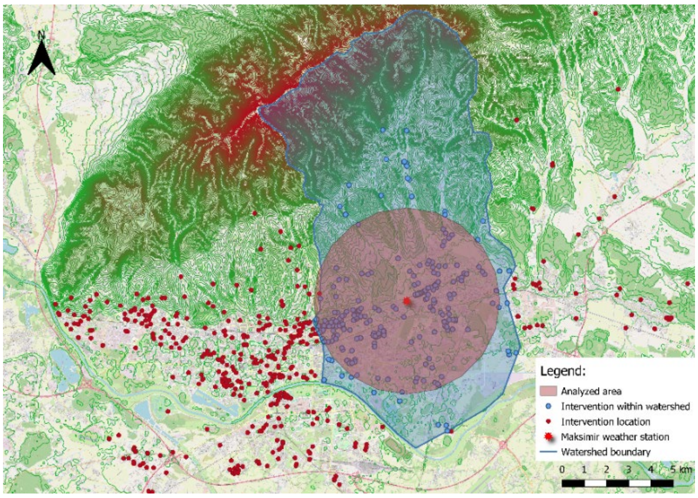

Fig. 1 Interventions recorded by the Public fire department of Zagreb from 2007 to 2017 related to rainfall events and analysed sub-area within the watershed boundary.

Results

Performed land use analysis of subbasin area established the relationship between urbanization and permeability of surfaces with surface runoff and flooding. Based on obtained reports from fire brigades about interventions, dates and addresses of water pumping interventions from facilities and open spaces, a cartographic database of interventions together with spatial land use analyzes was made, the result of which showed that most of the operations were related to residential (57%) and traffic areas (28%). On the other hand, the impact intensity, measured as the average number of operations per event, is highest for precipitation in the range of 35-40 mm/h, with 15.5 interventions per event. 764 rainfall events were analyzed (h+m+f+c). Of that number, 88 rainfall events were related to interventions (h+m), while 676 were not related to interventions (f+c) (Eq. 1-3). Both obtained thresholds, empirical and statistical, could be used for practice. However, the upper percentile threshold has sufficient correctness with more correct flood predictions and higher false alarm rates than the upper empirical threshold, while the lower percentile threshold has slightly better correctness than the lower empirical threshold. By fitting a trendline the upper thresholds based on empirical data is determined as $I = 23.189 \cdot D^{-0.701}$ [mm/h].

Conclusion

Critical thresholds for rainfall intensity and duration related to pluvial urban floods developed for this case study, could be of great help to public services so that appropriate protection and rescue measures can be planned and implemented by local and national government in a timely manner. A more detailed spatial analysis of flood impacts and flood hazard indicators should be conducted in future research in the city of Zagreb, and other approaches should be considered. It is also important that precipitation extremes are taken into account in the preparation of standards, especially when considering new infrastructure to prevent flood events in the future.

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References

Alfieri L, Salamon P, Pappenberger F, Wetterhall F, Thielen J (2012). Operational early warning systems for water-related hazards in Europe. *Environmental Science & Policy*, **21**, 35–49.

Cannon SH, Gartner, JE, Wilson, RC, Bowers, JC, Laber, JL (2008). Storm rainfall conditions for floods and debris flows from recently burned areas in southwestern Colorado and southern California. *Geomorphology*, **96**(3–4), 250–269.

Diakakis M (2012). Rainfall thresholds for flood triggering. The case of Marathonas in Greece. *Natural Hazards*, **60** (3), 789–800.

Ferreira C.S.S., Potočki K., Kapović-Solomun M., Kalantari Z. (2021) Nature-Based Solutions for Flood Mitigation and Resilience in Urban Areas. In: The Handbook of Environmental Chemistry. Springer, Berlin, Heidelberg. https://link.springer.com/chapter/10.1007/698_2021_758

Guzzetti F, Peruccacci S, Rossi M, Stark CP (2008). The rainfall intensity–duration control of shallow landslides and debris flows: an update. *Landslides*, **5** (1), 3–17.

Jang JH (2015). An advanced method to apply multiple rainfall thresholds for urban flood warnings. *Water*, **7**(11), 6056–6078.

Jelić L, Bekić D, Vouk D (2020) Urbane poplave u Zagrebu 2020. – stanje i potrebe. Građevinar : časopis *Hrvatskog saveza građevinskih inženjera*, **72** (9), 819–821.

Jha AK., Bloch R, Lamond J (2012) Cities and flooding: a guide to integrated urban flood risk management for the 21st century. The World Bank.

Jurković RS., Nimac I, Kalin KC (2019) Intensity-duration-return period (frequency) (IDF) curves: method of design and potential pitfalls. 7th CROATIAN WATER CONFERENCE WITH INTERNATIONAL PARTICIPATION, Opatija, Croatia

Hrastovski M (2016) Identifikacija pokretača poplava u Gradu Zagrebu-analiza oborinskih događaja 2013. i 2014. godine University of Zagreb, Faculty of Mining, Geology and Petroleum Engineering. Available online: https://urn.nsk.hr/urn:nbn:hr:169:198731(accessed in June 2018)

Ma, B., Wu, Z., Wang, H., Guo, Y. (2020). Study on the Classification of Urban Waterlogging Rainstorms and Rainfall Thresholds in Cities Lacking Actual Data. *Water*, **12** (12), 3328.

Papagiannaki K, Lagouvardos K, Kotroni V, Bezes A (2015). Flash flood occurrence and relation to the rainfall hazard in a highly urbanized area. *Natural Hazards and Earth System Sciences,* **15** (8), 1859–1871.

Potočki K., Bekić D., Bonacci O., Kulić T. (2021) Hydrological Aspects of Nature-Based Solutions in Flood Mitigation in the Danube River Basin in Croatia: Green vs. Grey Approach. In: The Handbook of Environmental Chemistry. Springer, Berlin, Heidelberg. https://link.springer.com/chapter/10.1007/698_2021_770

Potočki K, Vouk D, Kuspilić N (2018) Smanjenje rizika od poplava u urbanim sredinama pomoću integralnih zelenih rješenja. U: Holcinger, N. (ur.)Zbornik radova VII. Konferencija Hrvatske platforme za smanjenje rizika od katastrofa. Zagreb, Hrvatska

RAINMAN Project - Interreg. Available online: https://www.interreg-central.eu/Content.Node/RAINMAN.html (accessed on 25 September 2020)

Zanchetta AD, Coulibaly P (2020). Recent advances in real-time pluvial flash flood forecasting. *Water*, **12** (2), 570.

Climatology of the extreme heavy precipitation events in Slovakia in the 1951–2020 period

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Introduction

Ocean heating affects the dynamics of atmospheric flows and consequently, the processes of genesis, vertical and horizontal dimensions, stability, and patterns of movement of low- and high-pressure areas (Bintanja et al., 2013; Vihma, 2014). Warner (2018) proposes that there is a strong positive correlation between the October sea ice ecxtent and the DJF (December – January – February) values of the NAO index (North Atlantic index). This can, via presupossed stratospheric path, impact the strength of the polar stratospheric vortex, specifically to cause its weakening, which is subsequently manifested in the troposphere by weakening of zonal winds and more pronounced meandering the jet stream. This modifications in the synoptic scale atmospheric circulation might lead to a change in the distribution of precipitation during the year in Slovakia, displaying as an increase in the share of convective based stormy downpours in the total precipitation sums (Faško et al., 2015; Markovič et al., 2016) and the increasing extremity of precipitation events. In Slovakia, general studies have been previously published that dealt with multi-day precipitation totals (Lapin, at al. 2004; Stehlová, et al., 2001; Gaál et al., 2002; Jurčová et al., 2002) however, these studies using shorter time series of daily precipitation were mostly very localized and due to the limited number of precipitation stations with processed maximum multi-day precipitation totals and time-consuming process of obtaining this data, only limited set of precipitation stations with authentic data has been used in the analysis. Dynamic-climatological analysis of extreme precipitation events was previously published only for maximum 2-day precipitation totals (Markovič, 2019).

Methodology

Our study uses new authentic data set of Rx5d from 486 precipitation stations owned and operated by Slovak Hydrometeorological Institute (SHMÚ), with available, complete, and consistent time series of daily precipitation from the period 1951-2020. We investigate extreme heavy precipitation events in the Slovak Republic in the period 1951–2020 in terms of their spatial and temporal distribution with goal to create dynamic-climatological analysis of those patterns of the atmospheric circulation, that can eventually lead to the occurrence of the extreme multi-day precipitation events. Heavy precipitation is defined as maximum precipitation total over five consecutive days (Rx5d) where a non-zero daily precipitation total must be recorded every day of selected 5-day period. Our paper is constructed as an analysis of relationships between localized tropospheric circulation defined by the Czechoslovak catalogue of the typified synoptic situations (Brádka, 1968), the predominant wind patterns and the spatiotemporal distribution of Rx5d. The method used in the process of selecting significant Rx5d events was based on the analysis of average monthly values of the maximum multi-day totals earned in a given month for each year of analysis as simple mean of all station values. Process of defining the days, from which was each selected Rx5d situation constituted, was followed by assignment to the corresponding typified synoptic situation. Data sources selected for identification process were represented by specialized calendars of analyzed synoptic situations containing analysis on day-to-day basis. For the period 1951 - 1990 a calendar elaborated for the territory of former Czechoslovakia was used and since 1991 a calendar of situations identified exclusively for the territory of Slovakia was applied. For more accurate identification of atmospheric circulation also archived reanalyzed large-scale maps of geopotential levels 850 hPa and 500 hPa created by the US Global Circular Model - GFS and by the US Office for Ocean and Atmosphere (NOAA) were used.

Results

Spatiotemporal analysis of annual and seasonal maximum Rx5d points to the fact, that higher values in the period 1951–2020 of Rx5d were generally achieved in the warm half-year (April–September) with significantly pronounced orographic – windward and leeward effects during the cold half-year (October–March). The highest values of Rx5d exceeded 250 millimeters and were measured at precipitation stations located in the mountainous areas in the northern part of Slovakia at elevation over 600 meters amsl. Absolute maximum value of Rx5d,

accounted for 274,7 mm, was measured in May 2014 in Tatranská Javorina on the northern slopes of the Belianske Tatry mountain range.
Mean value of the maximum precipitation totals from the complete set of 486 precipitation stations used as a measure to detect the occurrence of the spatially significant precipitation events reached its highest values within the May – October period. The highest mean value was recorded in July 1997 with mean Rx5d value 80,7 millimeters. The highest mean values, independent of the month of occurrence, were recorded during the presence of the typified synoptic situations characterized as low-pressure trough (B/Bp) and cyclone over Central Europe (C) circulating types. Changes in the spatial distribution of Rx5d during the year were clearly identified in the separate warm half-year (April – September) and cold half-year (October – March) analyzes. Spatially significant precipitations events recorded in the warm half-year were, in more than 1/2 of the identified events, caused by the cyclonic situations with central position (C) (8% increase) and by the low-pressure trough (B/Bp). Cold half-year is, on the other hand, defined by a significant increase in influence of the cyclonic situations with northern orientation (Nc/NWc/NEc) complementing low-pressure troughs (B/Bp).

Conclusion

Our paper deals with the study of the maximum 5-day precipitation totals (Rx5d) in the Slovak Republic in the period 1951-2020 in terms of their spatial and temporal distribution with a goal to create basic dynamic-climatological analysis. Extreme Rx5d events with highest mean Rx5d values were recorded in the summer months and their occurrence is linked to the low-pressure trough and cyclone over Central Europe circulating types. Spatially significant changes in the position of the influencing synoptic types during the cold (March–October) and the war half year (April–September) were detected. Our analysis highlights the fact, that regional Czechoslovak typification of significant synoptic situations can, despite its often-present subjectivity, provide very good results that correlate with the long-term climatological knowledge of atmospheric circulation over the territory of Slovakia. It also provides god basis for the future objective dynamic-climatological analysis.

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References

Bintanja R, Van Oldenborgh, GJ, Drijfhout SS, Wouters B, Katsman CA (2013) Important role for ocean warming and increased iceshelf melt in Antarcticsea-iceexpansion, *Nature Geoscience* **6**, 376–379.

Brádka J, and HMI collective (1968) Typizace v meteorologii, Meteorologické Zprávy, Český hydrometeorologický ústav, Praha.

Faško P, Šťastný P, Švec M, Kajaba P (2015) Výskyt a priestorové rozloženie vysokých denných a viacdenných úhrnov zrážok na Slovensku, Manažment povodí a povodňových rizík 2015 a Hydrologické dni 2015, ÚH SAV, Bratislava.

Gaál L, Lapin M (2002) Extreme several day precipitation totals at the Hurbanovo observatory (Slovakia) during the 20th century. *Contributions to Geophysics and Geodesy*, vol. **32** no. 3, 197–213.

Jurčová S, Kohnová S, Szolgay J, Gaál L (2002) K výberu vhodnej distribučnej funkcie maximálnych 5-denných úhrnov zrážok, Acta Hydrologica Slovaca, ÚH SAV, Bratislava.

Lapin M, Gaál L, Faško P (2004) Maximálne viacdenné úhrny zrážok na Slovensku, Seminár „Extrémy počasí a podnebí “, Brno, 2004, ISBN 80-86690-12-1.

Markovič L, Faško P, Bochníček O (2016) Zmeny dlhodobých priemerných mesačných a ročných úhrnov atmosférických zrážok na Slovensku. *Acta Hydrologica Slovaca*, č. **2**, 2016, ÚH SAV, Bratislava, 235–242.

Markovič L, (2019) Dynamic-climatological analysis of the maximum 2-day precipitation totals in Slovakia. *Meteorologický časopis.* Bratislava: Slovenský hydrometeorologický ústav, **22**(1), 31-38. ISSN 1335-339X.

Wetterzentrale (2021) NOAA 20th century, online: https://www.wetterzentrale.de/en/reanalysis.php?model=noaa

Stehlová K, Kohnová S, Szolgay J (2001) Analýza dvojdňových úhrnov zrážok v oblasti horného Hrona, *Acta Hydrologica Slovaca*, vol. **2**, no. 1, 167–174.

Vihma T, (2014) Effects of Arctic Sea Ice Decline on Weather and Climate: A Review, Surveys in Geophysics, *Volume* **35**, Issue 5, 1175–1214.

Study of trends in the time series of flood runoff in the Tisza Basin Rivers within Ukraine

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Introduction

The rivers of the Tisza basin are characterized by a flood regime and flow through the territory of Western Ukraine, where the mountain system of the Eastern Carpathians is located, which is subdivided into the Outer Eastern Carpathians (the Carpathian rivers within the Dniester and Prut basin) and the Inner Eastern Carpathians (the Transcarpathian rivers – the Danube basin, namely the Tisza with tributaries). Almost all considered Mountain Rivers of Transcarpathia belong to the category of small rivers, however, the length of the studied rivers in 90% cases more than 10 km. The catchments are characterized by significant slopes (from 7.8 ‰ to 111 ‰) and an average elevation from 310 to 1100 m. The Ukrainian Carpathians are densely covered with forests, therefore, the forest cover of catchments on the rivers of Transcarpathia is 40–87%, but there are almost no swamps and lakes in the studied catchments. At the study territory, catastrophic floods are periodically observed, which lead to significant economic losses, and sometimes to human casualties. The floods of 1911, 1913, 1957, 1969, 1998, 2001, 2008 and 2020 can be classified as exceptionally high on the territory of the Ukrainian Carpathians (Margaryan et al., 2020).

Methodology. To analyze the initial information, the method of mathematical and statistical analysis, spatial generalization, extrapolation and correlation was used. To assess the statistical homogeneity of the initial information used three criteria: F-test (Fisher criterion), Student's t-test and Wilcoxon criterion. The assessment of cyclical fluctuations of maximal runoff is performed using the time siries trends, and statistical processing using the method of moments and maximum likelihood.

Results

The water gauge station (WGS) on river of Transcarpathia have an observation period from 56 to103 years, up to 2015 inclusive. According to the existing time series of observation of the maximum runoff in the territory of the Ukrainian Carpathians, the absolute values of the maximum water discharge in Transcarpathia vary from 86.7 m^3 / s (Kamenka river - Dora village, A = 18.1 km^2) to 5200 m^3 / s (Prut - Chernivtsi, A = 8690 km^2).To study temporal trends in chronological series of maximum runoff, chronological graphs of annual maximum water discharge on the rivers of the Tisza basin within Ukraine (Fig. 1) were constructed. Their analysis shows that both an increase (3 cases or 21%) and decrease in runoff (10 cases or 72%), and in some cases - invariability (1 case or 7%) in fluctuations in the maximum annual water discharge. Thus, there is no definite regularity in the distribution of trends in maximal runoff at the Transcarpathian region; for 3 catchments, there is a statistic significant trend towards a decrease in runoff and, for only 1 catchment, to an increase.The final stage of the work was the study of the patterns of change in the maximum annual discharge from the factors of the underlying surface - the areas of catchments and their average elevations. Analyzing the obtained dependences, it can be noted that for the rivers under consideration there is a regular decrease in the absolute maximum runoff modules with an increase in the catchment areas, the dependences are linear and are confirmed by significant correlation coefficients. On the other hand, taking into account that a mountainous region is being considered, the dependence of the investigated value on the average elevations of catchments was built - here there is a regular increase in the maximum runoff modules with an increase in the terrain elevation. The presence of such dependences opens up prospects for further research on the development of regional methods for determining the maximum annual runoff of ungauged rivers.

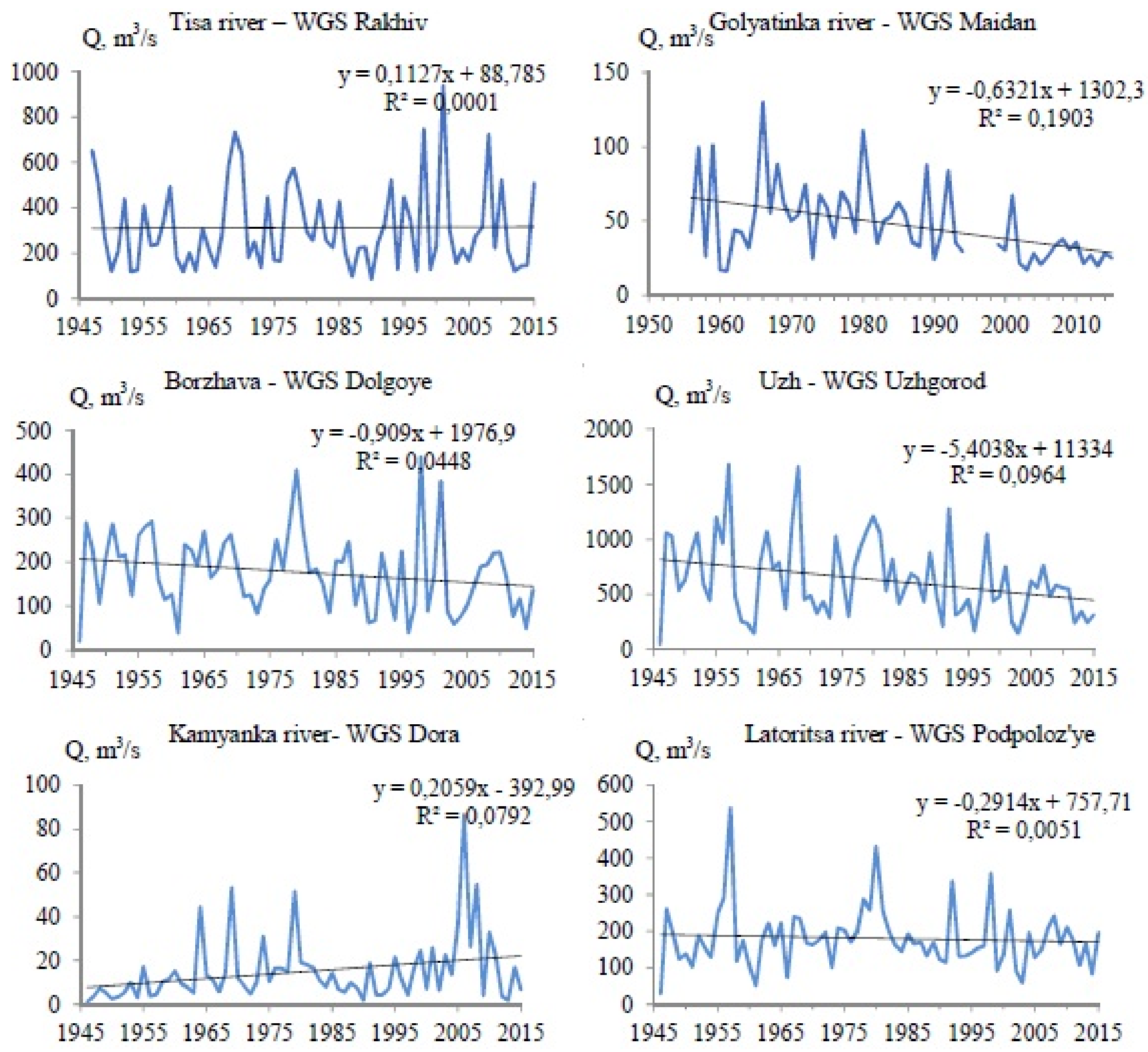

Fig. 1 Time series of maximal annual runoff at the river of Tisza basin within Ukraine.

Conclusion

• Studying the regularities of the formation of the maximum river runoff under the conditions of regional and global climate changes is an urgent task of modern hydrology;
• Analysis of data on annual flow maximums showed that for the Tisza basin within Ukraine, floods can be observed throughout the entire calendar year;
• Time trends in the multiyear maximum water discharges are not unambiguous. On the territory of Transcarpathia, in 70% of cases, there are trends insignificant to an increase or decrease, in 21% - a significant negative trend, and only at the Kamenka river - Dora village (A = 18.1 km^2) there is a significant positive trend;
• The presence of stable relationships between the annual maximums and the catchment areas of the rivers shows the possibility of developing a methodology for determining the maximum discharge of unexplored rivers in Transcarpathia.

References

Margaryan VG, Ovcharuk VA, Goptsiy MV, Borovskaia GA, (2020), Comparative analysis and estimate of the long-term fluctuations of the river maximum runoff of the mountain territories of Armenia and Ukraine under of global climate change, *Sustainable Development of Mountain Territories*, **12** (1), pp. 61–75

Estimated characteristics of the minimum water runoff of the rivers of the Tisza basin within Ukraine

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Introduction

The minimum water runoff study, which refers to the hazard hydrological period, and its calculated characteristics, is quite relevant nowadays. Minimum runoff indicators set limits on water consumption and drinking water supply, water use conditions in various sectors of the economy, protection of water resources from pollution and depletion, and sometimes are indicators of real danger and catastrophic water scarcity, in particular during prolonged droughts (Obodovskyi et al., 2019). These issues are critical in today's climate change, when the probability of extreme hydrological phenomena may increase significantly.
The purpose of the presented study is to determine the minimum water runoff has calculated characteristics of the Tisza basin rivers within Ukraine and to analyze its spatial distribution. The basis for this was previous and current research and current and retrospective data from observations of the minimum runoff of these rivers. The importance of attracting current data is that on the rivers in the study basin, like on Ukraine, in recent years, there has been a low water period (Grebin V. et.al., 2015).
The upper part of the Tisza basin is mostly within Ukraine, with a total catchment area of 12,8 thousand km^2. There are mountainous parts of the Carpathian Mountains (occupies about 25%, average heights of 800–1200 m abs.), foothills (40%, 200–800 m abs.) And Transcarpathian lowlands (35%, less than 200 m abs.). According to climatic conditions, the Tisza basin is one of the wettest part in Ukraine (average annual rainfall reaches 1200–1500 mm in the mountains and decreases in the lowlands to 700–800 mm) (Lipinsky V. et. al, 2003). The water regime of rivers is characterized by floods both in the warm (rain floods) and cold period (snow - rain floods). The traditional low water periods on the rivers of the Tisza basin are almost absent. Low runoff is recorded in the inter-flood periods, and there are different durations.

Methodology

Methods of mathematical statistics and probability theory were used to achieve the goal of this study (calculation of statistical parameters of the distribution of random variables, empirical and ordinates of analytical distribution to determine the studied values of different excesses, correlations and their estimation, etc.). Besides, for spatial analysis and construction of cartographic maps of low water runoff distribution was used GIS (QGIS) (Obodovskyi et al., 2019).
The study used data from water runoff observations from hydrometric stations both within Ukraine (48) and outside Ukraine (8). The Transcarpathian water balance station data were also used for a detailed consideration of the minimum water runoff. The duration of runoff observations is different, in the vast majority of 53-70 years — processed daily stock data from the beginning of observations until 2015 inclusive (Pochaievets et al., 2018, 2019).
The important methodological elements of the study are the choice of the studied characteristics (for the year or seasons), the duration of the periods of minimum water runoff. Regarding the studied characteristics, the minimum water runoff was considered separately for the summer-autumn and winter periods. From the calculated values, it is proposed to consider the minimum water runoff as the average for 7-days 80% of security. According to the intra-annual runoff distribution analysis, the Tisza basin is divided into two districts - eastern and western (Pochaievets et al., 2018).

Results

The distribution of the modulus of flow of the minimum water runoff for 7-days generally repeats the spatial distribution of the modulus of flow of the mean annual river water runoff (Obodovskyi et al.,2020). In general, its modulus of flow of minimum water runoff directly depends on the elevation of the terrain. Minimum values ($1\ \mathrm{l} \cdot \mathrm{s}^{-1}\mathrm{km}^{-2}$) are typical for the lower part of the Uzh river basin. Then it increase and reaches its maximums of 7 and 9 $l \cdot s^{-1} km^{-2}$, respectively, within the water balance station and near the tops of the sources of such rivers as the Black Tisza, Shopurka, Teresva. It is established that the variability of the minimum runoff in different seasons is almost the same. Coefficients of variation Cv for the summer-autumn season varies between 0.28–0.68, for winter – 0.30–0.67. Analysis of Cv's spatial distribution showed that greater variability is observed in the western region's rivers during the summer-autumn season. As for the eastern region, the runoff of water during the winter season is more unstable. The variability and instability of the minimum runoff during the summer-autumn season is explained by frequent and sudden floods, especially in the mountainous part of the basin. There is a tendency to increase the coefficient of variation with decreasing catchment height. For the summer-autumn season, the correlation coefficient r = 0.51, and for the winter season, r = 0.36, which indicates a weak relationship between these values. For both summer-autumn and winter seasons, the minimum water runoff for 7-days is less variable for hydrological posts located in mountainous areas with altitudes greater than 800 m. The established dependencies and connections allowed mapping the coefficients of variation and building a map of their distribution in the studied basin. Their territorial distribution showed that, in general, the lowest Cv values are characteristic of mountainous areas, and higher values are inherent in the plains, especially for the minimum runoff of the summer-autumn season. In the summer-autumn period, the variation coefficient decreases from west to east of the basin from 0,60 to 0,30. Regarding the winter period, then the minimum runoff is less variable. Higher values of the coefficient of variation are typical for more mountainous areas of the basin. There are mostly positive values in the whole basin about the asymmetry coefficient Cs, which indicates that the long-term variability in rivers is dominated by the values of minimum runoff, which are less than the average long-term. Based on the obtained values of 7-day minimum runoff of 80% exceedance probability of water for rivers of the studied basin, where observations are made, the transition coefficients are generalized, and the regression equation of transition from minimum water discharge of 80% of exceedance probability to 75, 90, 95, 97% of exceedance probability summer-autumn and winter seasons. The constructed map of the spatial distribution of the minimum water runoff modules of 80% of exceedance probability it possible to estimate the minimum water runoff of rivers of exceedance probability in the absence of observational data.

Conclusion

According to the calculations and analysis of the minimum water runoff's spatial distribution, taking into account the data of modern observations, it can be stated that similar previous studies, both temporal and spatial variability of the minimum water runoff in the Tisza basin within Ukraine. For the values of 7-day minimum runoff of 80% of water of exceedance probability for the rivers of the studied basin, the transition coefficients are generalized, and the regression equation of transition from minimum water runoff of 80% of exceedance probability to 75, 90, 95, 97% separately for summer-autumn and winter seasons. The results of the study are of practical importance, in particular, in the field of water management, hydraulic engineering and water use.

References.

Lipinsky V., Dyachuk V., Babichenko V. Climate of Ukraine (2003). Kyiv: Raevsky Publishing House. 343 p.

Grebin V., Boyko V., Adamenko T. (2015) Hydrological drought of 2015 in Ukraine: factors of formation, course and possible consequences. *Hydrology, hydrochemistry and hydroecology*. V. **3**. S. 44–54.

Obodovskiy O., Lukianets O., Pochievets O., Moskalenko S. (2019) Long-term variability of the absolute annual minimum water flow of the rivers of Ukraine. Visnyk of Taras Shevchenko National University of Kyiv: *Geology*. V. **4** (87). pp. 89–95. http://doi.org/10.17721/1728-2713.87.13

Pochaievets O., Obodovskyi O. (2018) Assessment of the influence of the main hydrographic characteristics of the water

catchments of the rivers of the Tisza basin (within Ukraine) on the formation of the minimum flow. . *Hydrology, hydrochemistry and hydroecology*. V. **4** (51). p. 76–86.

Pochaievets O., Obodovskyi O. (2019) Use of GIS to estimate the spatial distribution of the minimum water runoff of the rivers of the yew basin within Ukraine. *Physical geography and geomorphology*. **№4**. P.18–25.

Obodovskyi O., Pochaievets O., Grodzinskyi M., Melnyk A. (2019) Modern approaches to constructing maps of the minimum flow of the mountain rivers (the case of the Tisza rivers basin within Ukraine). AIP Conference Proceedings 2186, 120016; https://doi.org/10.1063/1.5138047

Obodovskyi O., Lukianets O., Konovalenko O., Mykhaylenko V. (2020). Mapping the Mean Annual River Runoff in the Ukrainian Carpathian Region. *Journal of Environmental Research, Engineering and Management.* Vol. **76** / No. 2. pp. 22–33 DOI 10.5755/j01.erem.76.2.20916.

Climate Change Implications for the Flow Characteristics of Two Karst Catchments in Slovenia

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Abstract

In two karst catchments that are part of the larger Ljubljanica river catchment, the analysis of the future low and high flows according to climate change projections was done. Despite the uncertainty of the models, some conclusions can be drawn, especially regarding the occurrence of extreme events associated with high flows.

Introduction

Recent investigations show that climate change, reflected in rising air temperatures, will affect flow dynamics (Blöschl et al., 2017). Global models under different scenarios show a consistent picture of rising temperatures, but on the other hand, there is still a lot of ambiguity present regarding the reflection of changes in precipitation. Consequently, there is still a lot of ambiguity about the effects of rising air temperature on changes in water resources especially at local and catchment scale (UNESCO, 2020). This paper describes the main findings of the study in terms of changes in the properties of low and high flows with respect to different climate change projections (Sapač et al., 2019). The research was conducted in one smaller and one larger karst catchment in Slovenia, where approximately 1/3 of the population depends on the karst water resources.

Methodology

The study was conducted in a Nanoščica river catchment (Mali otok water station, 50 km^2) referred to as a small catchment and Ljubljanica river catchment (Vrhnika water station, 1135 km^2) referred to as a large catchment. For the hydrological model, we used daily rainfall data, reference evapotranspiration, and air temperature. For the calibration of the hydrological model, daily discharge data from Mali otok and Vrhnika stations were used in the period 1981–2010. For the Ljubljanica river catchment and Nanoščica river catchment, CemaNeigeGR6J and GR6J models of IRSTEA group were used, respectively (Valéry et al., 2014a, 2014b). Regarding the climate change modeling, we focused on the representative concentration pathway 4.5 (RCP4.5) referred also as a moderately optimistic scenario suggesting that greenhouse gas emission will gradually decrease in the second half of the 21st century (IPCC, 2014). In the analysis, five different combinations of global and regional climate models were included and used for the investigation of changes in precipitation, air temperature, and evapotranspiration. For every variable of model data (i.e. precipitation, air temperature, and evapotranspiration), bias correction was made. Climate change implications for the flow characteristics of both catchments were evaluated based on the several low- and high-flow indices: baseflow index (BFI), mean annual minima for the duration of 7 and 30 days (MAM7, MAM30), flows that are exceeded 50% and 95% of the time (Q50, Q95), date of the low-flow occurrence (D), seasonality ratio (SR) (WMO, 2008), discharge with a 10-, 50-, and 100-year return period (T10, T50, T100). The mentioned indices were evaluated for periods 2011–2040, 2041–2070, 2071–2010 and their median values were relatively compared with indices evaluated for the reference period 1981–2010.

Results

For both catchments, it was found that we could expect a decrease of minimum discharges, especially Q95, in the future. Moreover, in both catchments, the analysis of seasonality of low flows revealed that their occurrence could be shifted towards late summer or autumn. Regarding the high flows, differences between catchments were found. In the larger catchment, we could expect an increase of floods with a 10-year return period (T10) in all three future periods. However, the pattern for floods with 50- and 100-year return periods is not so clear. On the other side, in the smaller catchment increase of extreme flows for up to 30% could be expected in all three future periods (Fig.

1). This may suggest that smaller karst river catchments are more vulnerable in terms of the impacts of climate change on flows and water availability.

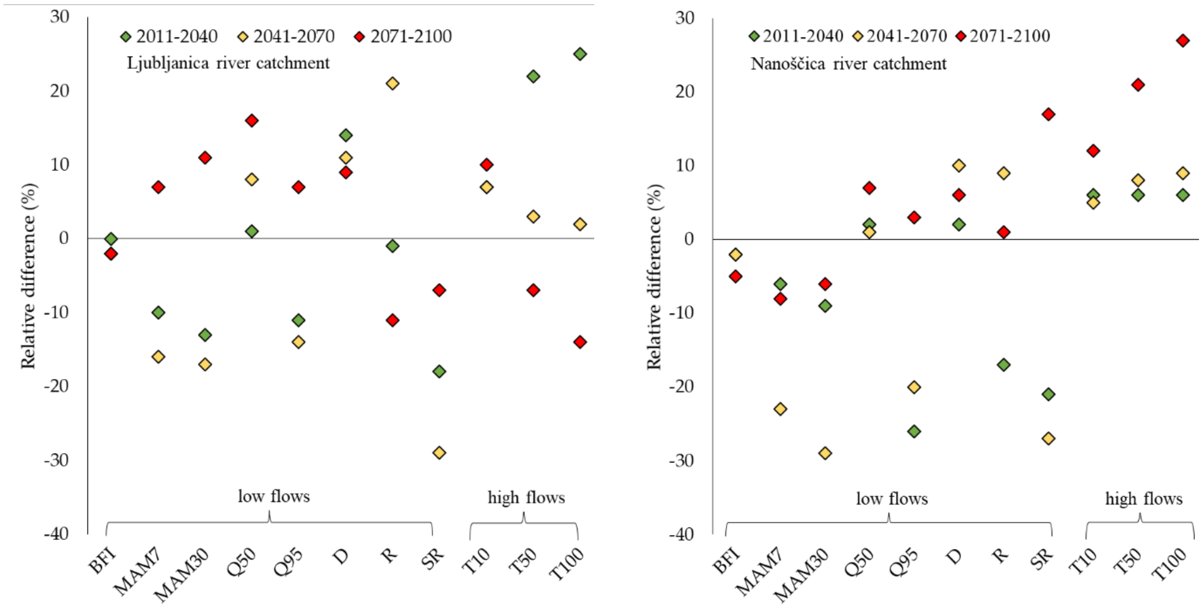

Fig. 1 Relative difference of median values of low- and high-flow indices based on the 1981–2010 period. Different colours of the dots represent different comparative period in the future.

Conclusions

From the analysis, some general conclusions can be drawn for the hydrological situation of the smaller and larger catchments in the future. Climate models showed a decrease of precipitation in the summer months in 2011–2040 and 2041–2070 periods, which can be consequently reflected in lower flows. The latter was confirmed by indices MAM7, MAM30, and Q95. Accordingly, this may affect the availability of karst water resources in this region. While low flows are expected to decrease in the future, Q50 and Qmean showed an increasing trend, which could result in a higher magnitude of extreme high-flow events. Results of flood frequency analysis for both catchments confirmed this. Last but not least, it is important to consider great uncertainty when using the results of this and other similar studies where different climate models and projections are used. As also follows from the study Sapač et al. (2019), five used climate models with just RCP4.5 scenarios demonstrated high variability of results for both low and high flows.

Acknowledgements

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References

Blöschl G, Hall J, Parajka J, et al. (2017) Changing climate shifts timing of European floods. *Science* **357**, 6351, 588–590. https://doi.org/10.1126/science.aan2506

IPCC (2014) Climate Change 2014 Part A: Global and Sectoral Aspects, Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1132 pp.

Sapač K, Medved A, Rusjan S, Bezak N (2019) Investigation of low- and high-flow characteristics of karst catchments under climate change. *Water* (Switzerland) **11**, 5, 925. https://doi.org/10.3390/w11050925

UNESCO (2020) Water and Climate Change – The United Nations World Water Development Report 2020. Paris, UNESCO, 219 pp.

Valéry A, Andréassian V, Perrin C (2014a) As simple as possible but not simpler: What is useful in a temperature-based snow-accounting routine? Part 2 - Sensitivity analysis of the Cemaneige snow accounting routine on 380 catchments. *Journal of Hydrology*, **517**, 1176–1187. https://doi.org/10.1016/j.jhydrol.2014.04.058

Valéry A, Andréassian V, Perrin C (2014b) As simple as possible but not simpler: What is useful in a temperature-based snow-accounting routine? Part 1 - Comparison of six snow accounting routines on 380 catchments. *Journal of Hyrology*, **517**, 1166–1175. https://doi.org/10.1016/j.jhydrol.2014.04.059

WMO (2008) Manual on Low-flow Estimation and Prediction, Operational Hydrology Report. WMO, Geneva, Switzerland, 136 pp.

Hydrological Modelling for Water Balance Components Assessment

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Introduction

Water balance is a well acknowledged technique for analyzing the hydrology of a watershed. Quantifying the parameters of the hydrological cycle is the first step for estimating water resources and water balance. Due to the complex character of hydrological processes the usage of hydrological models is widely recognized as an effective tool for understanding and representing the relationship between different processes and water balance parameters. Hydrological models identify the dominant hydrological processes which influence water balance (Yordanova et al., 2020). Hydrological models delineate the partition of water input to a watershed (mainly rainfall) into hydrological processes – surface run-off, base flow, ET and storage changes. The water balance components that are commonly interpolated for WRA purposes are the characteristics of precipitation and runoff (WMO, 1992a). In this study SWAT (Soil Water Assessment Tool) hydrological model was applied to Vit river basin to estimate the water balance components of the catchment – surface run off, lateral flow, evapotranspiration, etc.

Methodology

Study area

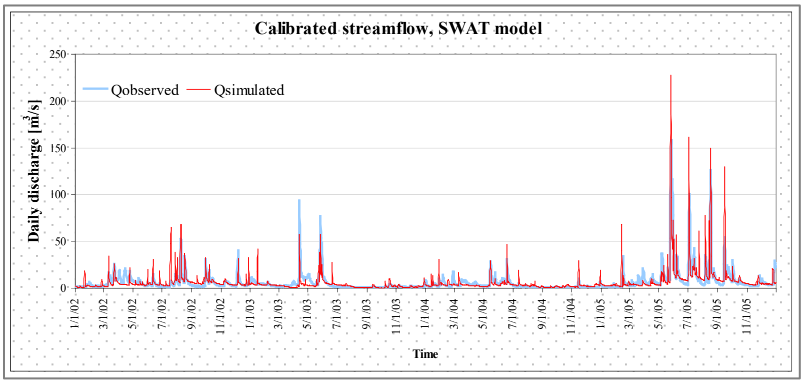
The study area (Vit river watershed) is located in northern Bulgaria and is part of the Danube river basin. Vit river catchment is elongated with an area of 3225 km2. The river begins after the confluence of the Beli Vit and Cherni Vit rivers, both springing from the Balkan Mountain. The slope of the river in the mountainous part of the watershed reaches up to 200 ‰. The mainstream goes on directly northward through large valley with lower slope to the Danube river. The average slope of Vit river is 9.6 ‰. The density of the river network is very small – 0.5 km/km2. The average altitude of the watershed is about 400 m. There are five monitoring hydrometric stations and nine monitoring meteorological stations in the watershed.

Methods and materials

In this study the Soil and Water Assessment Tool was used (Arnold et al., 2012). SWAT is an open source watershed scale, semi-distributed hydrological model. It uses physically-based input such as topography, soil properties, land cover and weather data to evaluate temporal and spatial variability of water cycle parameters. For modelling the spatial variability of the watershed SWAT divides it into subwatersheds, each of them further subdivided into hydrologic response units (HRUs) by overlaying the slope map, generated from the DEM with the soil and land use maps. The major components, such as soil water content, surface runoff, streamflow and etc. are calculated for each HRU before being aggregated by a weighted average for every subbasin (Gassman et al., 2008). For setting up the model spatial data set was processed includng a digital elevation map (DEM), landuse and soil maps. Meteorological data* i.e. daily precipitation, maximum and minimum daily temperature, daily relative humidity and daily wind speed was also collected and processed. Daily river discharge data* at the five monitoring hydrometric stations was used for model calibration and validation. *Hydrometeorological data sets for the period 2000-2010 were provided by the National Institute of Meteorology and Hydrology in Bulgaria.

Results

After the initial simulations a sensitivity analysis was performed and the model was calibrated. The accuracy of the calibrated model results was evaluated at the outlet of the watershed by using different statistical indicators. Calibrated SWAT model showed a good temporal streamflow representation (Fig.1), Nash-Sutcliffe coefficient (NSE) was 0.74 and the correlation coefficient (R2) was 0.76. SWAT-based water balance component calculations after calibration (Fig.2) showed that ET has the highest share of the water balance with a value of 49%. Revap (1%) and lateral flow (6%) have the lowest percentage of all. The results indicate that surface water availability is considerable.



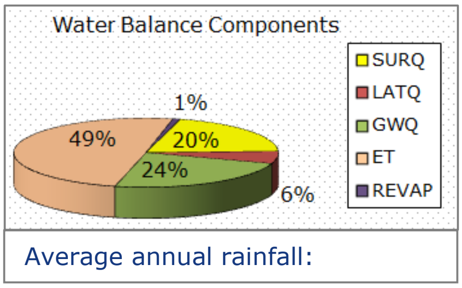


Fig.1. Calibrated streamflow

Fig.2. Water balance components

Conclusion

Simulation results are subject to further validation and further improvements in model performance should be sought.

Additional land cover analysis is required during the available period of rainfall-run-off record to establish a statistically valid link between changes in land cover and hydrological response (Baker et al, 2012).

Applying precise parameterization for SWAT model greatly improves model simulation results. An in-depth understanding of the hydrological processes as well as model parameters is needed for setting-up a reliable hydrological model.

Spatial and temporal characteristics of the observed daily discharge data were properly represented by SWAT. The high values of the statistical estimates R^2 and NSE for calibration period imply SWAT model is useful in studying hydrology and estimating water balance components and water yield in the study watershed.

References

Arnold, J. G., Moriasi, D. N., Gassman, P. W., Abbaspour, K. C., White, M. J., Srinivasan, R., et al. (2012). SWAT: model use, calibration, and validation. Trans. *ASABE* **55**, 1491–1508 pp

Baker, Tracy, Miller, Scott. (2013), Using the Soil and Water Assessment Tool (SWAT) to assess land use impact on water resources in an East African watershed, *Journal of Hydrology* **486**, 100–111 pp

Frederick Ayivi, Manoj K.Jha (2018) Estimation of water balance and water yield in the Reedy Fork-Buffalo Creek Watershed in North Carolina using SWAT, *International Soil and Water Conservation Research*, Volume **6**, Issue 3, 203–213 pp

Philip W. Gassman, Manuel R. Reyes, Colleen H. Green and Jeffrey G. Arnold (2008), The Soil and Water Assessment Tool: Historical Development, Applications and Future Research Directions, Special Publication No 4 by The World Association of Soil and Water Conservation, 25-93 pp

World Meteorological Organization (1997), Water Resources Assessment Handbook For Review Of National Capabilities

Yordanova, V., Stoyanova, V. (2020), Modeling floods with a distributed hydrological model in a river catchment, International Multidisciplinary Scientific GeoConference Surveying Geology and Mining Ecology Management, 249–255 pp

Public awareness about floods – High water marks

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Introduction

In the year 2014 Slovenian Environment Agency and Ministry of the Environment and Spatial Planning together with Association of Slovenian Geographers initiated the placement of high water marks on rivers, lakes and sea. The aim of the action is to inform the has inhabitants of the natural phenomenon of high waters, improve their knowledge of the impoundment of karst poljes, flood prone areas near rivers and raise awareness that, more or less frequently, the water needs its natural extended space (ie. floodplains). Besides the official institutions, local stakeholders are crucial (local population, schools, local government, real estate owners of buildings with the installed high water marks), are also included in the campaign.
The main purpose of the action is the encouraging of critical judgment of one's own and others' actions, while raising the individual's sense of responsibility in case of floods. Purposes such

- informing of high waters
- education about floodplain
- raising public awareness - to remind of the fact that water more or less often requires space for itself,

are of great importance for preparation of long-term and sustainable River basin management plans and also for Spatial plans on regional level. The campaign is linked to the guidelines of the Water (Water Framework Directive, 2000) and the Floods Directive (Directive, 2007). Both are based on the principles of sustainable development and sustainable spatial planning.

Methodology

The action started in 2014 and it is ongoing activity. It represents good cooperation between government institutions, regional and local institutions, universities and schools as well as local communities (Frantar et al., 2016). In the last seven years, more than 60 high water marks (see Fig.1) have been placed. For placement of each high water mark it is necessary to follow few steps:
1. To determine when and to what height the floodwater reached at a certain high water event; discuss this with the local population, schools, associations, municipalities…
2. To find the right building or object to place the mark that is exposed and publically accessible, visible and frequently visited.
3. To get permission from the real estate owner of the building or object to place the mark.
4. To coordinate the installation with the local stakeholders and prepare the public event with media coverage.
All installed high water marks are entered in the database and displayed online http://gis.arso.gov.si/atlasokolja/profile.aspx?id=Atlas_Okolja_AXL@Arso

Results and conclusions

The Action of placement of high water marks is all about linking the "fragmented" activities of public institutions, the economy, the societies and local communities to manage water resources responsibly and improve high water safety. It is about intergenerational integration, connecting sectors with the educational system and local communities and civil protection for the responsible management of water resources in the local environment. It is an innovative, direct field approach to raise public awareness for responsible management and adaptation to the changed dynamics of fresh water and the sea. This approach received the highest rating from the International Commission for the Protection of the Danube River (ICPDR) and the International Sava River Basin Commission as a way to emulate. Our marks are already placed along the Mura River in cooperation with Austria and on Sotla River (see Fig.2) in cooperation with Croatia and ICPDR.

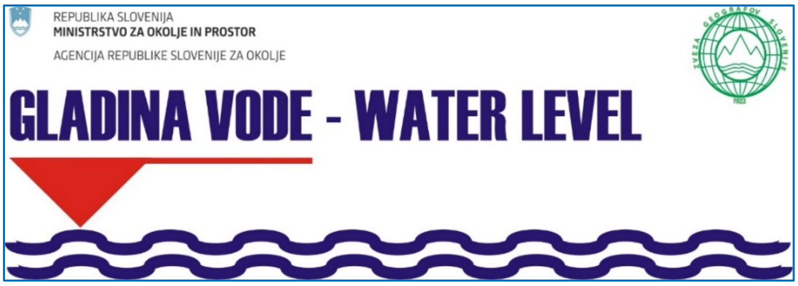

Fig. 1 High water mark

Fig. 2 Placement of the high water mark on the Sotla River

References

Frantar P., Ulaga F., Bat M., Jarnjak M (2016). Akcija postavljanja oznak visokih voda v Sloveniji, *Ujma*, **30**, 166–170.

Water Framework Directive (WFD), Directive 2000/60/EC of the European Parliament and of the Council establishing a framework for the Community action in the field of water policy.

Directive 2007/60/EC of the European Parliament and of the Council of 23 October 2007 on the assessment and management of flood risks.

Future flood risk in the Danube basin: A probabilistic assessment

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Introduction

Consistent information on fluvial flood risks in large river basins is typically sparse. This is especially true for the Danube River basin, where multiple countries create a patchwork of flood risk information across a populous and flood-prone region. Transboundary risk assessment and management is required to implement the solidarity principle, which is an important request of the EU Floods directive. As climatic changes have shown to increase the risk of flooding in the future, consistent basin-scale assessments prove vital to the insurance industry as well as municipal and infrastructural planning.

Methodology

Here, a probabilistic assessment is presented using the Future Danube Model (FDM), which was designed to fill this gap complying with both insurance-industry and climate-science standards. The FDM consists of a modular chain of modelling tools including a stochastic weather generator, a hydrological and a hydrodynamic model to produce discharge and water level time-series as well as inundation depth and inundation duration maps, and a vulnerability model which translates flood intensity in combination with information about exposed assets into economic loss estimates. It simulates fluvial flooding over the entire basin at a detailed model scale (based on a 25m digital elevation model) and pluvial flooding in selected cities. It uses stochastic sampling to create a large number of extreme events (10k years) and associated flood footprints for the past and two future time horizons as well as two climate change scenarios (RCP4.5 and RCP8.5) and four EURO-CORDEX climate model combinations. All model components have undergone thorough calibration and validation. The flood footprints are passed on to a state-of-the-art loss and damage model that represents the uncertainty associated with flood vulnerability estimates. All components are encoded in an open-source modelling framework (OASIS-LMF), an open-source standard widely accepted in the insurance industry.

Results and conclusions

Results indicate a marked increase in flood recurrence in most parts of the basin already in the near future (2020–2049) compared to the reference period (1970–1999) with further increases at the end of the century. In large parts of the basin, the historical 100-year peak discharge is projected to increase by approx. 10–20%, while the historical peak is projected to be equalled or exceeded every 50–10 years. Residential and commercial areas with a 100-year flood risk are projected to increase by 15–26% (depending on flood protection and climate scenario). Fluvial flood losses to residential buildings in the reference period are estimated to amount to some €12 billion for a 100-year flood event and are projected to increase by 25–40% for the near and far future under RCP8.5. Hungary and Romania were found to see the largest climate-change induced increases in losses. While these numbers are subject to large uncertainty, this assessment demonstrates the value of integrated, high-resolution modelling approaches, co-designed with potential end users, to inform public and private risk management.

Flood frequency analysis for Ukrainian and Austrian Danube tributaries

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Introduction

Flood frequency analysis (FFA) is the estimation of how often specific flood events will be exceeded. Flood frequency hydrology is based on the analysis of the stream or river flow data to obtain the probability distribution of flood (Merz, 2008a). One of the statistical approaches that are mostly used to model flood data and often provide the best fit is the Gumbel's distribution. The aim of this study is to compare the magnitude of design winter floods (November-April) in two similar Danube regions (in Ukraine and Austria) using Gumbel's distribution. For this analysis the return period (T) considered are 2-, 5-, 10-, 50-, and 100-years.

Data and methodology

Study area

This study was carried out for small and medium size Ukrainian (14 gauges in the upper Rika river basin) and Austrian (10 gauges in the upper Steyr river basin) unaffected mountainous catchments of the Danube river basin in the period 1952–2016. The mean catchment elevation for Austrian catchments is slightly higher (951 to 1506 m a.s.l.) than for Ukrainian catchments (from 747 to 1000 m a.s.l).

Assessment of the homogeneity and stationarity of hydrological time series

The basic assumptions for the application of FFA of the maximum annual flow peaks (Q_{max}) series are: 1. The observations in the data series shall be identically distributed, statistically independent and random; 2. Q_{max} measurements are stationary with respect to time (data series homogeneity). This requires that the river has not been regulated within the duration of the time series, i.e. not affected by human modifications such as reservoir, urbanization etc. Observed flow data available for more than 10 years with good quality are deemed sufficient for the estimation of discharge values associated to low return periods. The assessment of the homogeneity and stationarity of time series was carried out by the hydro-genetic approach (Gorbachova, 2014).
Gumbel distribution

The density function of the Gumbel distribution is:

$$f(x) = \frac{1}{d}\exp\left(-\frac{x-c}{d}\right)\cdot\exp\left[-\exp\left(-\frac{x-c}{d}\right)\right] \quad (1)$$

where x – random variable, c and d – parameters. The cumulative distribution function is:

$$F(x) = \exp\left[-\exp\left(-\frac{x-c}{d}\right)\right] \quad (2)$$

The quantile function is:

$$x_T = \mathrm{c} - \mathrm{d}\cdot\ln\left[-\ln\left(1-\frac{1}{T}\right)\right] \quad (3)$$

where T – return period and the parameters estimated based on the method of moments are:

$$d = \frac{\sqrt{6}}{\pi}\cdot\sigma \text{ and } c = \mu - 0.5772\cdot d \quad (4)$$

where μ – mean, σ – standard deviation, *0.5772* – Euler-Mascheroni constant.

Results

Flood frequency analysis shows that the largest flood discharge in the upper Rika river basin was the event of 1958, which corresponds to an empirical T of 60 years (in outlet gauge Rika River at Mizhhiria village), and for upper Steyr river basin – 1962 (T=66 years, in outlet gauge Steyr River at Klaus an der Pyhrnbahn). The estimated design flood Q_{100} using Gumbel distribution are presented in Table 1.

Table 1. *List of catchments, catchment area (km²), largest observed winter flood (Q_{max}, m³/s) and estimated design flood with 100-yr return period (Q_{100}, m³/s).*

Gauge	Area	Q_{max}	Q_{100}	Gauge	Area	Q_{max}	Q_{100}
UA:Rika R - Mizhhiria v	550	735	569	UA:Ziubrovets S - Lopushne v	3.2	5.53	4.49
UA:Rika R - Verkhnii Bystryi v	165	142	117	UA:Serednii Zvir S - Lopushne v	2.2	2.97	2.25
UA:Holiatynka R - Maidan v	86	127	97.5	AT:Steyr R - Klaus an der Pyhrnbahn	545	420	377
UA:Pylypets R - Pylypets v	44.2	57.1	67.3	AT:Teichl R - St. Pankraz	231	156	163
UA:Lopushna R - Lopushne (n.) v	37.3	43.9	33.6	AT:Steyr R - Kniewas	190	102	106
UA:Studenyi R - Nyzhnii Studenyi v	25.4	52.6	33.2	AT:Teichl R - Teichlbrücke	147	129	114
UA:Ploshanka S - Pylypets (n.) v	19.9	30.3	34.6	AT:Steyr R - Hinterstoder	86	56	53.2
UA:Lopushna R - Lopushne (v.) v	13.2	13.4	12.7	AT:Steyrling R - Steyrling	72	82	70
UA:Branyshche S - Lopushne v	10.3	16.7	13.3	AT:Dambach R - Windischgarsten	66	55	51.2
UA:Studenyi R - Verkhnii Studenyi v	8	12.3	9.67	AT:Teichl R - Spital am Pyhrn	39	22.9	20.9
UA:Pylypets R - Podobovets v	7.4	17.6	20.7	AT:Steyr R - Dietlgut	26	15.3	15.1
UA:Pylypetskyi S - Pylypets v	5.7	8.12	9.17	AT:Krumme Steyr R - Polsterlucke	18	20.7	22.7

v. - village, R - River, S - Stream, UA - Ukrainian catchment, AT - Austrian catchment, n. – nyzhnii, v. - verkhnii.

The estimated design floods with 100-yr return period are found to be larger for Ukrainian catchments compared to Austrian catchments (Fig. 1a). The proportion of catchment area covered by forest shows a large variety between catchments (Fig. 1b). The comparative analysis of the frequency flood curves of all study catchments of the Austrian and Ukrainian basins show that for most gauges the observed peaks deviate significantly from the Gumbel's curve for floods with higher return periods. For instance, Fig. 1c shows two flood frequency curves for the outlet of the analysed catchments in Ukraine and Austria. The flood frequency curves for the tributaries look very similar both for Ukraine and Austria.

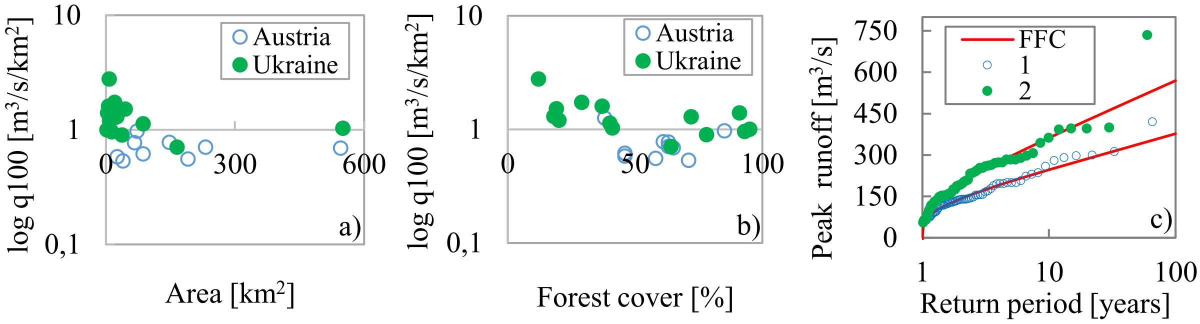

Fig. 1. *Design floods with 100-year return period scaled with catchment area as a function of catchment area (a) and forest cover (b); selected flood frequency curves (c) (points – observed peaks vs empirical return period) in the upper Steyr (1-Steyr River – Klaus an der Pyhrnbahn) and upper Rika (2-Rika River - Mizhhiria village) river basin.*

Conclusion

Floods with 2 yrs, 5 yrs, 10 yrs, 50 yrs and 100 yrs return periods were estimated for all the study catchments using the Gumbel's distribution. For the majority of the Ukrainian and Austrian catchments, the flood frequency curves fit the observations very well for lower floods but the fit is not that good for floods with higher return periods. It found that the floods are larger in the upper Rika river basin in Ukraine than in the upper Steyr river basin in Austria.

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References

Gorbachova L (2014) Methodical approaches the assessment of the homogeneity and stationarity of hydrological observation series, *Hydrology, Hydrochemistry and Hydroecology*, **5** (32), 22–31 (in Ukrainian)

Merz R, Blöschl G (2008a) Flood frequency hydrology: 1. Temporal, spatial, and causal expansion of information, *Water Resources Research*, **44**, 8, article number W08432, 17 pp.

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