KATHOLISCHE UNIVERSITÄT EICHSTÄTT-INGOLSTADT

43rd IAD Conference

Rivers and Floodplains in the Anthropocene – Upcoming Challenges in the Danube River Basin

June 9-11, 2021

- Proceedings -

edited by:

Bernd Cyffka, Florian Betz, Tim Borgs, Marion Gelhaus, Barbara Stammel , Mira Vontz

Aueninstitut Neuburg/Donau
Schloss Grünau
86633 Neuburg/Donau
Germany
aueninstitut@ku.de

Preface

Dear Readers,

These conference proceedings have resulted from the 43rd Conference of the International Association of Danube Research (IAD). This conference series has always been a meeting point for research teams from the Eastern and the Western Danube River Basin, facilitating knowledge exchange as well as joint projects and publications in the region. In 2021, the IAD celebrated a special event. For 65 years, it has continuously been present in limnological, river and floodplain research in the Danube River Basin. The Covid-19 pandemic forced the organization of an online event. Nevertheless, there was an awesome engagement of more than 100 participants with many fruitful discussions.

The 43rd IAD Conference was dedicated to the manifold challenges the Anthropocene poses to the rivers and floodplains in the Danube River Basin. The topics of the conference were as diverse and interdisciplinary as river science itself, ranging from hydrobiology to flood protection to policy related issues. The articles in this conference volume reflect this diversity of topics. In addition, they also represent the international character of the Danube River Basin being the most international river basin of the world. Researchers and practitioners from Germany, Austria, Hungary, Croatia, Serbia, Romania and Bulgaria are among the contributing authors.

Bringing together all these experiences from various scientific backgrounds and different countries highlights the relevance of the IAD for cooperation in the Danube River Basin and gives hope for jointly meeting the challenges of the Anthropocene.

The Editorial Team

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Hydrological indicators of the riverbed incision along the free-flowing Danube River reach from Budapest to Slankamen relevant for the lateral connectivity between the river channel and floodplains

TAMÁS, EA[a], ĐORĐEVIĆ, D[b], KALOCSA, B[c], VUJANOVIĆ, A[d]*

[a] *Faculty of Water Sciences, University of Public Service, Baja, Hungary*
[b] *Faculty of Civil Engineering, University of Belgrade, Belgrade, Serbia*
[c] *Palustris Co., Baja, Hungary*
[d] *Institute of transportation CIP Ltd, Belgrade, Serbia*

* *Corresponding author:* tamas.eniko.anna@uni-nke.hu

Abstract

Hydrological regime plays a primary role in the sustainable management of floodplains, as floodplain ecosystem dynamics and balance are largely dependent on the dynamics of the flow regime of rivers. In the 1980's a drying process of floodplains on the lower Danube reach in Hungary became evident while in the 2000s continuous unimpeded water supply of the main canal network in the Danube-Tisza-Danube water supply and drainage canal system became an alarming problem. In view of these problems, the present analysis aims at: 1) recognising hydrological indicators of the incision and/or aggradation of the riverbed, 2) estimating the extent of these processes and the rate of change of the riverbed in time based on these indicators, as well as 3) estimating possible consequent changes in the frequency of extremities. The study has shown that the lateral connectivity is at risk along the whole reach as the deepening of the riverbed still continues and according to some parameters (e.g. the gradient of decrease of mean water levels) is even increasing.

1. Introduction

The motivation for this analysis stems from the observed drying of the floodplain forests along the Hungarian reach of the Danube River that became evident in the late 1980ies and problems in water supply of the main canal network in the Danube-Tisza-Danube canal system in Serbia in the last two decades. Since the floodplain ecosystem dynamics and balance are strongly related to the dynamics of the flow regime of a river, the causes of the drying process of Hungarian floodplain forests (Zsuffa 1993) were sought through the comprehensive hydrological statistical analyses (Kalocsa 1992) published first in Kalocsa and Zsuffa (1997). All these statistical analyses indicated the lowering of the water levels in the active channel of the Danube River, which was explained by the incision of the riverbed. River training works and dredging were recognized as the main reason for the incision.

To the authors' knowledge, no comprehensive analysis of the changes in the water regime for the entire alluvial reach of the middle Danube has been made to date. To fill this gap, authors analyse available time series of the water level and discharge data for the free-flowing alluvial reach of the Danube River. The investigated reach is more than 300 km long, and spans from rkm 1581 in Dunaújváros, Hungary to rkm 1255 in Novi Sad, Serbia.

Fig. 1: Map of the free-flowing alluvial reach of the Danube River with the locations of GSs and main nature reserve Danube floodplains

The overall aims of this study are expected to reveal the causes of the disruptions in lateral connectivity between floodplains and the main river channel.

2. Statistical analyses

2.1 Data and software

Statistical analyses were performed by using time series of water levels and discharges in the 70 years long period between 1950 and 2019. The official water level and discharge data of the Hungarian Hydrological Forecasting Service and the Republic Hydrometeorological Service of Serbia for 5 gauging stations (GS) on the free flowing alluvial reach in each country were analysed. These are: Dunaújváros (rkm 1581), Dunaföldvár (rkm 1560), Paks (rkm 1531), Baja (rkm 1479) and Mohács (rkm 1447) in Hungary, and Bezdan (rkm 1425), Apatin (rkm 1402), Bogojevo (rkm 1367), Bačka Palanka (rkm 1299), and Novi Sad (rkm 1255) in Serbia. The annual extremes and means were used to analyse trends in change of minima, means and maxima, while the daily data from GS at Baja and Apatin in the same period were used to analyse trends in change of occurrence frequency of extremities. More precisely, the eventual changes of the inundation frequencies of the protected floodplain areas have been determined

On the Hungarian part of the investigated reach, there is the Gemenc Region of the Danube Drava National Park near Baja, most of it is a floodplain. Similarly, Kopački rit and Gornje podunavlje Nature Reserves in Croatia and Serbia respectively are in the Apatin region. All three areas are a part of the Mura-Drava-Danube Biosphere Reserve and they are protected on the national level in the three countries (Hungary, Serbia and Croatia) (Fig. 1). Parts of these areas belong to the Natura 2000 Network as well, and they are listed as wetlands of International Importance under the Ramsar Convention. Threshold levels for inundation of the Gemenc floodplain, Gornje podunavlje and Kopački rit were taken from Tamás & Kalocsa 2020, the Official Gazette of Serbia, and Tadić et al. 2014, respectively. Annual discharge data were analysed for GS at Baja, Bezdan and Bogojevo.

For data organization and trend analyses, MS Excel was used. Further statistical analyses were performed using XLStat (Addinsoft 2021) as well as U.S. Army Corps of Engineers Hydrologic Engineering Center's (HEC) Statistical Software Package (HEC-SSP).

2.2 Analysis methods

Since extensive river training works were performed along the studied reach to facilitate navigation along the Rhine–Main–Danube corridor, the statistical analysis started with testing of the homogeneity of annual time series of minima, means and maxima for all stations. The Kolmogorov-Smirnov test was used. The testing was performed using XLStat (Addinsoft 2021). This was followed by the distribution fitting analysis that was carried out in the HEC-SSP. All trend analyses of the annual values were done using a linear regression with LSQ method in MSExcel. The same software was used for further analyses, which included the investigation of the exceeding frequencies of the inundation thresholds of the protected floodplain areas along the reach, and the analysis of average water level changes.

3. Results and discussion

As already mentioned, it was necessary to test homogeneity of time series first. The homogeneity test was performed for the confidence level $\alpha = 0.05$. Test results for water levels are presented in Table 1. It is readily noticeable that the homogeneity of the time series is seriously affected along the entire reach except at Novi Sad, where the backwater effects of the Iron Gate I HPP start to play a role in the shaping of water levels, especially during low water flow (Babić-Mladenović et al. 2013).

The causes of the inhomogeneity are:

1) river training works, especially numerous cutoffs along the Hungarian stretch, which shortened the reach, changed energy balance and sediment transport capacities,
2) the extensive dredging activities in Hungary in the second half of the 20th century (Tamás 2006) and
3) 69 upstream reservoirs, which were built between 1950 and 1980 (Habersack et al. 2016).

All these activities led to a significant sediment deficit and morphological changes of the riverbed that affected the homogeneity.

Annual minima are the most affected as they have the greatest *D*- and the smallest *p*-values (Table 1). Between GS at Dunaújváros and Paks, where the mentioned extensive dredging activities were carried out, the *p*-values are not traceable/detectable (they are < 0.0001). What is interesting is that the time series of annual maxima are homogeneous almost along the entire reach, except at Dunaújváros, presumably because the effects of the regressive erosion are persistent.

Kolmogorov-Smirnov test for the distribution fitting has shown that all annual data - minima, means and maxima fit Pearson III distribution the best. The test was conducted with $\alpha = 0.05$. Due to limited space, values of Pearson III statistics and Kolmogorov-Smirnov test statistics are presented in Table 2 only for four GS that are relevant for the assessment of the connectivity of the floodplains with the main river (Table 2).

Time series of annual minimum, mean and maximum water levels for the 70 years long period between 1950 and 2019 (Fig. 2) clearly indicate that the observed decreasing trend of annual minimum and mean values on the Hungarian reach (Kalocsa 1992, Kalocsa & Zsuffa, 1997 and Goda et al., 2007) continued (Fig. 2). Savić and Bezdan (2009) observed also the decreasing trend on the Serbian section at the Bezdan GS. Time series in Fig. 2 show that this trend exists along the entire length of the free-flowing middle Danube reach, except for annual minima at Novi Sad where Danube enters the Iron Gate reservoir.

The most prominent decreasing trend is at the upstream part of the reach from Dunaújváros to Paks where the bed material changes from the fine gravel to the coarse sand. It exists for both annual extremes and the means. The decrease reduces for minima and means along the sand-bed alluvial reach starting from Baja GS. However, gradients for maxima do not show this regular behavior. It is interesting to notice that the annual mean water levels exhibit the fastest decrease (compare "a" columns in Table 3 and all three graphs in Fig. 2). Since the annual minimum, mean and maximum discharges show no trend – they are constant, or almost constant (parallel to the time axis, see Fig 3), the continuous lowering of the annual water levels can be explained by the incision of the riverbed.

Table 1: Results of the homogeneity testing, a = 0.05

Gauging Station	Minima			Means			Maxima		
	D-value	*p*-value	can be considered homo geneous	*D*-value	*p*-value	can be considered homo geneous	*D*-value	*p*-value	can be considered homo geneous
Dunaújváros	1.000	< 0.0001	NO	0.943	< 0.0001	NO	0.343	0.033	NO
Dunaföldvár	0.971	< 0.0001	NO	0.857	< 0.0001	NO	0.257	0.197	YES
Paks	0.714	< 0.0001	NO	0.543	< 0.0001	NO	0.159	0.837	YES
Baja	0.457	0.001	NO	0.400	0.007	NO	0.114	0.976	YES
Mohács	0.457	0.001	NO	0.429	0.003	NO	0.086	1.000	YES
Bezdán	0.371	0.016	NO	0.371	0.016	NO	0.114	0.976	YES
Apatin	0.429	0.003	NO	0.371	0.016	NO	0.114	0.976	YES
Bogojevo	0.429	0.003	NO	0.429	0.003	NO	0.171	0.683	YES
Bačka Palanka	0.257	0.255	YES	0.357	0.038	NO	0.121	0.976	YES
Novi Sad	0.229	0,320	YES	0,171	0.683	YES	0.114	0.976	YES

Table 2: Pearson III distribution statistics and Kolmogorov-Smirnov test statistic for distribution fitting

Gauging Station	Minima				Means				Maxima			
	Mean	**StDv**	**Skew**	**K-S test stat.**	**Mean**	**StDv**	**Skew**	**K-S test stat.**	**Mean**	**StDv**	**Skew**	**K-S test stat.**
Baja	81.70	0.52	0.26	0.078	83.85	0.64	0.51	0.074	87.64	1.17	0.45	0.058
Mohács	80.17	0.50	0.19	0.066	82.32	0.65	0.40	0.082	85.90	1.10	0.39	0.069
Apatin	79.46	0.50	0.32	0.054	81.67	0.62	0.43	0.059	84.89	0.97	0.43	0.056
Bogojevo	78.01	0.47	0.32	0.059	80.03	0.61	0.47	0.077	83.05	1.13	0.26	0.053

Table 3: Minima, means and maxima trends Z = a YEAR + b*

Gauging Station	Minima			Means			Maxima		
	a	**b**	**R^2**	**a**	**b**	**R^2**	**a**	**b**	**R^2**
Dunaújváros	-0.0254	140.42	0.77	-0.0270	145.13	0.68	-0.0105	115.42	0.03
Dunaföldvár	-0.0385	164.30	0.81	-0.0370	162.98	0.75	-0.0208	134.04	0.09
Paks	-0.0210	126.83	0.58	-0.0223	131.30	0.39	-0.0149	120.38	0.05
Baja	-0.0129	107.35	0.27	-0.0156	114.80	0.24	-0.0070	101.45	0.01
Mohács	-0.0110	102.02	0.21	-0.0183	118.54	0.23	-0.0112	107.98	0.03
Bezdán	-0.0105	101.56	0.20	-0.0139	110.45	0.21	-0.0020	90.39	0.00.
Apatin	-0.0101	99.56	0.17	-0.0131	107.58	0.18	-0.0006	86.11	0.00
Bogojevo	-0.0090	95.97	0.15	-0.0140	107.84	0.22	-0.0079	98.66	0.02
Bačka Palanka	-0.0026	79.83	0.02	-0.0082	92.80	0.11	-0.0016	82.27	0.00
Novi Sad	0.0051	62.06	0.06	-0.0049	83.98	0.04	-0.0009	78.73	0.00

Further statistical analysis included study of the multi-annual averages of minimum and mean water levels. The 10 year averaging period provided the best insight into the incision dynamics (Fig. 4). During the first decade after World War II (1950-59) either no changes (in the upstream reach with numerous cutoffs) or the increase in minimum and mean water levels (in the downstream sand bed reach) was observed. This could be explained by the fact that there were no river training works during the War. The post War growth of economy required better flood protection and the improvement of the water and ice conveyance as well as the navigability along the Danube River became an issue. This intensified river training works on both Hungarian and Serbian sections, which promoted continuation of temporarily stopped decrease in water levels. This is in line with the results of 15-years averaging by Kalocsa & Zsuffa, 1997 and Goda et al., 2007 on the Hungarian reach.

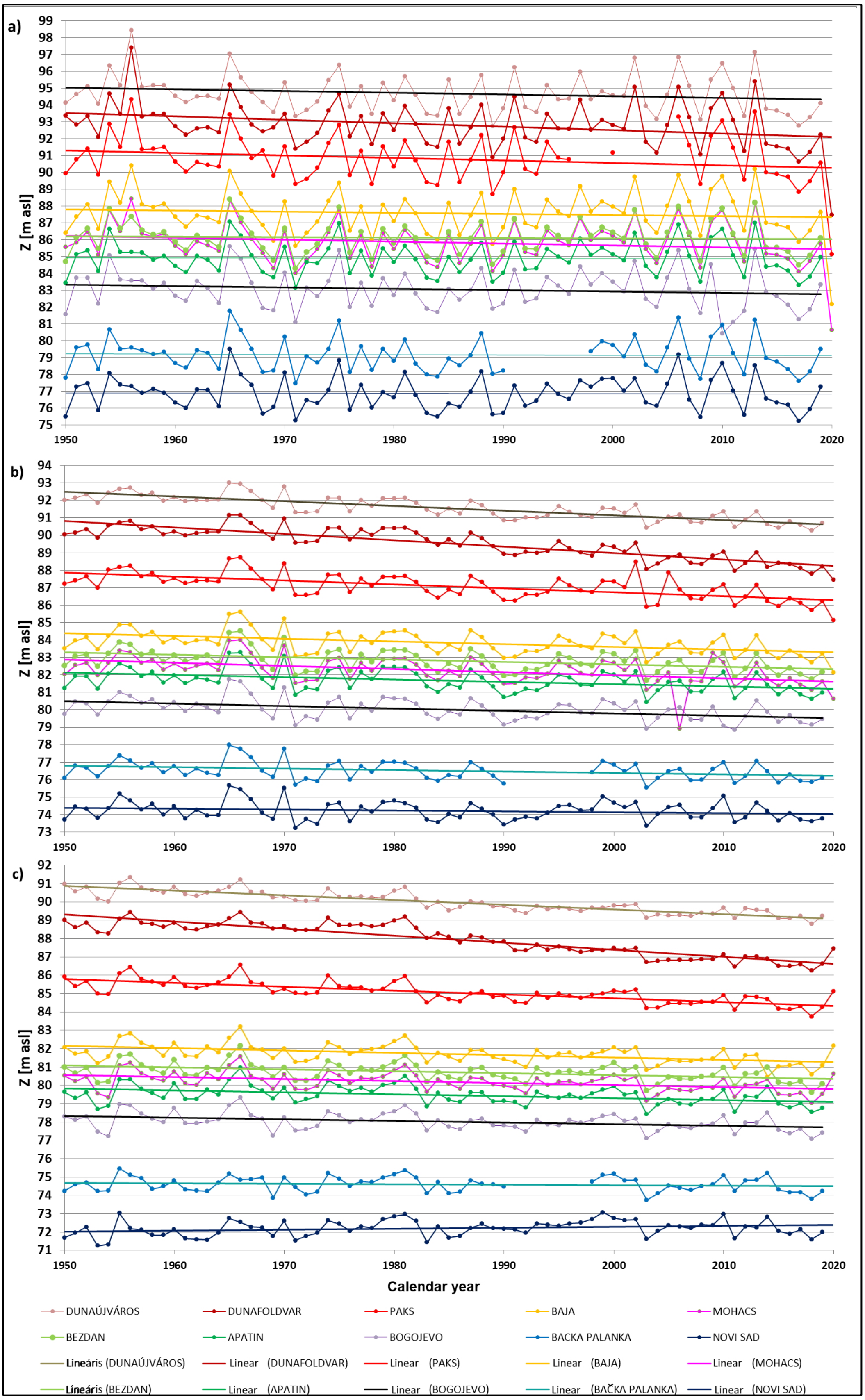

Fig. 2: Annual a) maximum, b) mean and c) minimum water levels with linear trends

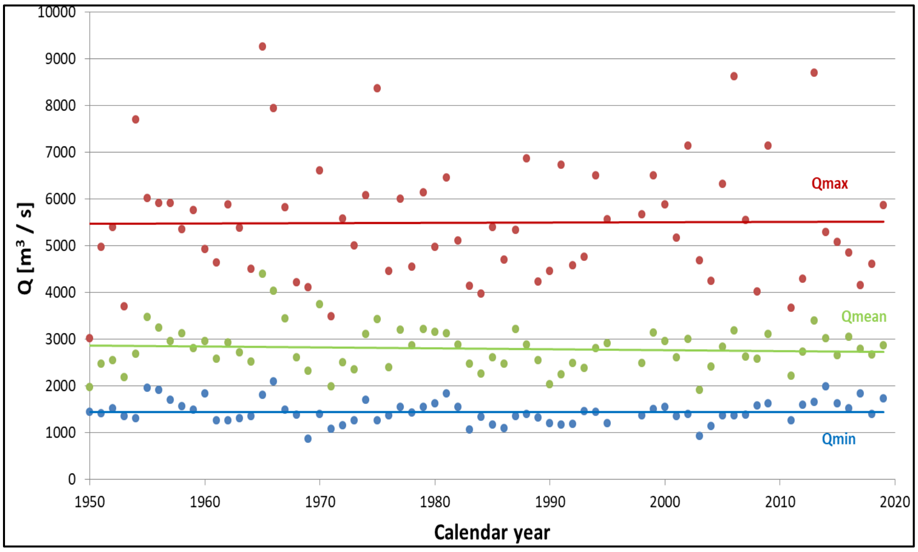

Fig. 3: Discharge minima, means and maxima at Bogojevo

Similarly to Mohács, the minimum water levels in the Serbian reach were lowering at an almost constant rate from Bezdan to Bogojevo. Changes were almost stable at Bačka Palanka, while the increasing water levels in Novi Sad started to decrease in the last two decades. Unlike minimum levels, which exhibit almost steady decrease, the mean levels manifest gradient steepening in the last decade.

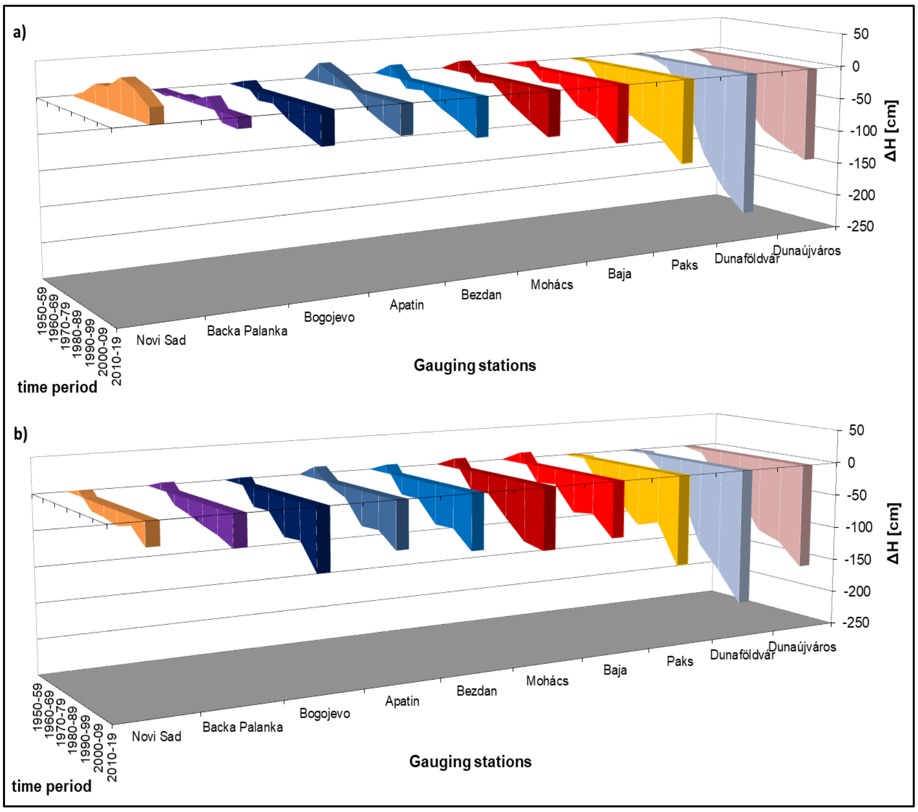

Fig. 4: Changes of a) annual minimum and b) annual mean water levels, 10-years averages

The effect of changes in the riverbed (of the active river channel) on the lateral connectivity can be best described by the changes in frequencies of the exceedance of threshold levels of inundation of the protected floodplains (Fig. 5) during 70 years.

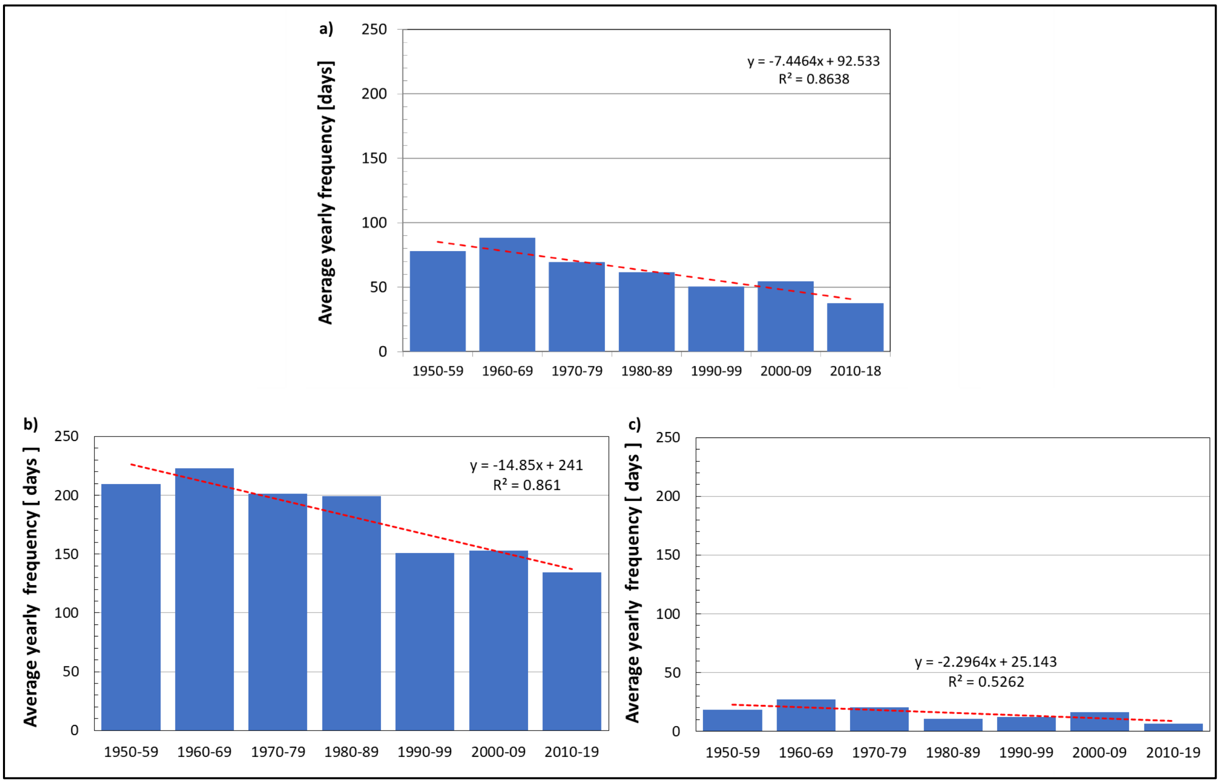

Fig. 5: Ten-years averaged frequencies of inundation threshold exceedance for a) the Gemenc floodplain in Hungary (Z = 85.3 m a.s.l. at Baja), b) Kopački rit in Croatia (Z = 81.5 m a.s.l. at Apatin) and c) Gornje podunavlje in Serbia (Z = 84.5 m a.s.l. at Apatin)

It is readily noticeable that the inundation frequencies most drastically decrease in Kopački rit, which has the lowest inundation threshold elevation among the three investigated protected floodplain areas. The inundation is 2 months shorter at the end of the 70-years period than in the beginning, decreasing from over 200 to a yearly average of 134,3 days. In Gemenc, this decrease is on average 1 month from 1950 to 2019, being now only 37 days, also comparable to previous findings: 172 days average inundation of the Gemenc area in the beginning of the 20th century, decreasing at an alarming rate to 58 days at the end of the 20th century (Kalocsa & Tamás 2003). Because of much higher elevations, the inundation frequency of Gornje Podunavlje is considerably lower, not being so much affected by the recent changes, but still decreasing.

4. Conclusion

According to the Water Framework Directive (WFD) the „good status" of the Danube River reach must be achieved. As the river and its floodplains constitute a complex ecological system, this can only be done through the harmonisation of the nature protection aspect reconstruction projects, WFD programmes of measures, flood management measures and navigation development.

If traditional river training activities continue, riverbed erosion will persist or increase in the future, resulting in slow, but continuous drying of floodplains that are very important nature conservation areas. Consequently, the majority of floodplain reconstruction works' effects might become negligible, while navigation problems will remain unsolved.

In the EU Floods Directive, natural flood management is an important issue, with a focus on increasing water retention capacities by e.g. the re-connection of rivers with their floodplains and the restoration of wetlands which can store flood water and help "slow the flow" of flood waters. In this respect, lateral connectivity is one of the most essential issues, as it is for the species inhabiting floodplains and rivers. However, floodplain lateral connectivity is already severed by the decreasing frequency and extent of inundation. The studied hydrological regime is the most important determinant of floodplain habitats.

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