Water quality evaluation of the Danube River basin in Bačka (northern Serbia) using multivariate statistical techniques

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ABSTRACT The study aimed to analyze changes in water quality based on ten physicochemical parameters for the Danube River in Bačka. Data from three profiles over a twenty-year interval were used and processed using multivariate statistics. An ANOVA indicated that the quality of surface water is mostly at a satisfactory level. Sufficient amounts of dissolved oxygen indicate a favorable aeration regime. The surpassing of the annual and monthly values of suspended solids was recorded for all profiles (especially in summer). The summary results show that most parameters, except for suspended solids, are within the allowed values for water quality Class II. A Pearson's correlation test indicates a moderate to weak correlation of the analyzed parameters. A PCA analysis determined the influence of (a) eutrophication processes; (b) ecological factors; and (c) concentrated sources of pollution. Changes in the Danube's water quality, primarily increased concentrations of suspended solids, can exert a limiting influence on some economic activities and their planning.

KEY WORDS water quality – Danube River – multivariate analysis – suspended solids – economic activities – Bačka

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1. Introduction

One of the most significant issues of the twenty-first century is the preservation and wise use of water resources, which are regarded as the most significant component of the environment and the cornerstone of sustainable development. Quality, quantity, and ecological state are the three factors that define water as a resource. When referring to water quality, physical-chemical, chemical, and biological indicators are used to describe the condition of aquatic ecosystems (Córdoba, Martínez, Ferrer 2010; Pantelić et al. 2013). Both anthropogenic (agriculture, industry, urbanization) and natural factors (tectonic conditions, topography and lithology of the terrain, climatic conditions, hydrography, and erodibility of the terrain) contribute to quantitative and qualitative changes in the physical and chemical parameters of water quality (Damo, Icka 2013; Zemunac et al. 2021). When human activity and heavy urban expansion result in the contamination of water resources, anthropogenic impacts can have detrimental effects within a short period of time (Yunus, Nakagoshi 2004; Dragićević et al. 2010). The availability of water for diverse uses (water supply, irrigation, industry, recreation, etc.) is the aim of the effective management of water resources. In such circumstances, the deterioration of water quality reduces its use value, which negatively affects the development of the area and the life of the local population (Fulazzaky 2010). Therefore, the monitoring of water quality parameters is a priority in the management of water resources at the global and local level.

The problem of pollution of the Danube was noticed relatively late, at the end of the 1980s, due to the negative effect of chemical substances on the aquatic world, especially the ichthyofauna (Navodaru, Staras, Cernisencu 2001; Stanić et al. 2006). The key issues with the quality, chemistry, and biological state of the surface and groundwater in the Danube basin have been identified by the Action Plan for the Danube Region (SWD 2020). The Danube River Protection Convention signed in 1994 is a legal instrument for cooperation and transboundary water management, and it led into establishing the International Commission for the Protection of the Danube River, ICPDR (2006). The ICPDR has been finally established in 1998 in Vienna and took part in the implementation of the Danube River Protection Convention (ICPDR 2005). The Joint Danube Survey 1 (JDS1) was carried out in 2001 and its results were a key information source for characterization of the Danube River Basin District (DRBD). ICPDR has organized The Joint Danube Survey 2 (JDS2) during 2007. The JDS2 successfully sampled 96 sites on the Danube river and 28 on its tributaries. Its main goal was to produce highly comparable and reliable information on water quality and pollution for the entire Danube river and many of its tributaries. Water pollution is a major problem in the Danube River Basin (DRB). Danube governments need to make sound decisions about what future measures they will take to reduce Danube pollution and improve ecological health. This will help them to meet their obligations to implement the Danube River Protection Convention, as well as the EU Water Framework Directive (WFD) with its aim to protect and restore the European water environment via participatory and integrative river basin management. WFD is widely regarded as the most ambitious and comprehensive piece of EU environmental legislation to date (ICDPR 2002, 2007a; Directive 2000). JDS2 identifies the main pressures on the Danube basin's environment and found main pollution sources related to the municipalities, industry and agriculture. Pollution really starts affecting water quality after Budapest. Upstream in Austria and Germany, point source pollution is low because of major recent investments in wastewater treatments plants. The positive impact is that overall pollution has declined, mainly because of the drop in industry and agriculture in Central and Eastern Europe following political transformations in the late 1980s. However, with expected economic improvements in these countries, pollution could increase. Pollution still remains high, especially from nutrients and hazardous substances (ICDPR 2007b). Numerous authors have investigated the issue of the Danube's water quality as it flows through Serbia (Durlević 2020; Leščešen et al. 2018; Milanović, Kovačević-Majkić, Milivojević 2010; Mladenović-Ranisavljević et al. 2012; Ocokoljić, Milijašević, Milanović 2009; Takić et al. 2012; Takić et al. 2017; Walker et al. 2015) and Autonomous Province (AP) of Vojvodina (Milanović, Milijašević, Brankov 2011; Milovanović et al. 2019; Pantelić et al. 2013; Pantelić et al. 2015; Salvai et al. 2022; Zemunac et al. 2021).

In recent years, numerous multi-criteria methods such as AHP – Analytic Hierarchy Process (Sutadian et al. 2017), ANP – Analytic Network Process (Yousefi, Zahedi, Niksokhan 2018), PROMETHEE – Preference Ranking Organization Method for Enrichment Evaluation with GAIA interactive module or geometry module GAIA Analysis for interactive help have been used (Mladenović-Ranisavljević et al. 2021). Apart from the mentioned statistical procedures, due to ease of use, an indicator such as WQI – Water Quality Index is often used (Stričević et al. 2021). Numerous multivariate statistical techniques, such as one-factor analysis of variance (ANOVA), Pearson's correlation and principal component analysis (PCA), are the most commonly used methods in the assessment of spatio-temporal changes in water quality (Garizi, Sheikh, Sadoddin 2011; Monica, Choi 2016), as well as the main sources of pollutants (Unda-Calvo et al. 2020). Since the mentioned multivariate methods are reliable and quite simple to interpret the results (Schreiber et al. 2022), they were given priority during the assessment of the Danube water quality parameters.

This paper aims to determine the surface water quality of Danube river basin in region of Bačka (Northern Serbia). In details, the water quality and its ecological status were assessed through temporal trends on anual and monthly scale at three different locations along the sector of Danube river in Bačka. The objective of the paper is to establish the potential sources of contamination and impacts of selected parameters on economic activites in this important economic region of the Republic of Serbia. The results are expected to help evaluate the temporal changes of Danube river water quality and enable better river management. Hereby, in the policy of future planning and regional development, the results can provide insight to understanding the main types of pollution at the different locations along the river basin.

2. Study area

The Danube river crosses the Hungarian-Serbian border at 1.433 km from its mouth at Sulina and at an altitude of 80.7 m above sea level, while it leaves the state territory at 845 km, at the mouth of Timok, at only 28 m above sea level. Therefore, the river course of the Danube flows through Serbia on a length of 588 km, where Bačka belongs to 218 km of the entire river course, i.e. 36.3% (Figure 1).

In fact, the entire Pannonian part of the country's territory is drained by the Danube, i.e. belongs to the Black Sea basin and along the entire length of its course through the province, the Danube belongs to the Pannonian sector. However, the course of the Danube through Bačka has three sectors: the first sector – from the state border towards Hungary to the mouth of the Drava, the second is from the mouth of the Drava to Novi Sad and the third is from Novi Sad to the mouth of the Tisa and the Danube (Gavrilović, Dukić 2014).

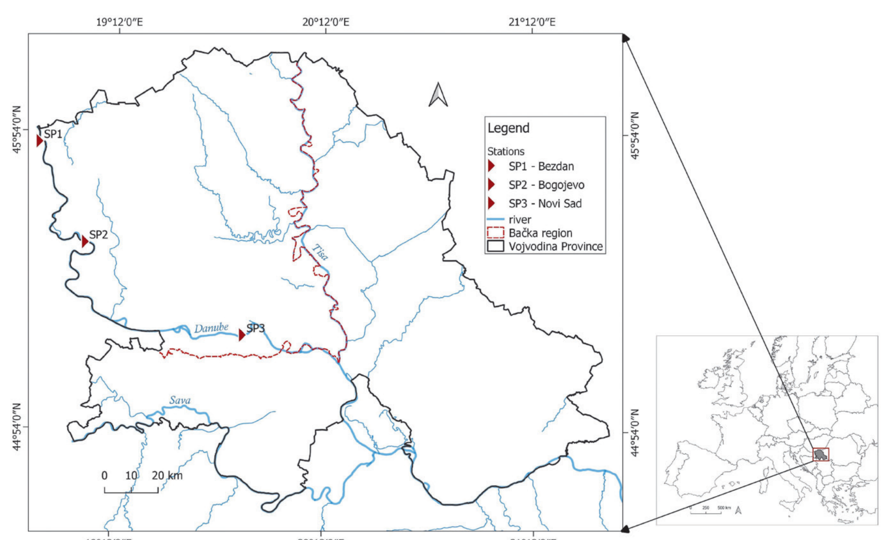

Fig. 1 – Location map of the study area with the distribution of sampling points (SP1–SP3) on the Danube river basin in Bačka. Source: created by the authors.

3. Data and Methods

3.1. Data

The data of the Republic Hydrometeorological Institute of Serbia (RHMS 1999–2018) for a twenty-year interval were used in the interpretation of the existing state of water quality in the Danube sector in Bačka. The paper analyzed water quality parameters taken from three profiles: Bezdan (SP1), Bogojevo (SP2) and Novi Sad (SP3; Fig. 1). Sampling of physical and chemical parameters was performed on a monthly basis. The following physical and chemical parameters of water quality were determined and analyzed: water temperature (°C), pH value, electrical conductivity (EC), dissolved oxygen (DO), biological oxygen consumption (BOD_5), suspended solids (SS), nitrates (NO_3-N), nitrites (NO_2-N), orthophosphates (PO_4-P) and ammonium ion (NH_4-N). The parameters' values were established based on the aforementioned information, and they were classified into classes I–V in accordance with the acceptable limit values (Official Gazette of RS, No. 50/2012; Table 1). Mathematical and statistical analyzes were performed in data were analyzed using the Statistical Package for the Social Science (SPSS; IBM 2017).

3.2. Methods

The results were analyzed based on several different statistical procedures applied in similar researches: descriptive statistical analysis (Pantelić et al. 2012), ANOVA analysis (Deng et al. 2022), Pearson correlations (Kharake, Raut 2021; Ahmed et al. 2022) and PCA analyses (Maji, Chaudhary 2019). The post-hoc Scheffe's test was

Table 1 – Limit values of selected surface water quality parameters

Parameter	Measurement unit	Class I	Class II	Class III	Class IV	Class V
pH	/	6.5–8.5	6.5–8.5	6.5–8.5	6.5–8.5	< 6.5 or < 8.5
Electrical conductivity	[µS/cm]	< 1.000 (or NL)*	1.000	1.500	3.000	> 3.000
Dissolved oxygen	[mg/l]	8.5 (or NL)	7	5	4	< 4
BOD_5	[mg/l]	2 (or NL)	5	7	25	> 25
Suspended solids	[mg/l]	25	25	/	/	/
Nitrates (NO_3-N)	[mg/l]	1 (or NL)	3	6	15	> 15
Nitrites (NO_2-N)	[mg/l]	0.01 (or NL)	0.03	0.12	0.3	> 0.3
Orthophosphates (PO_4-P)	[mg/l]	0.02 (or NL)	0.1	0.2	0.5	> 0.5
Ammonium ion (NH_4-N)	[mg/l]	0.1 (or NL)	0.3	0.6	1.5	> 1.5

Source: created by the authors according to the values determined in Official Gazette of RS, No. 50/2012.
Note: *NL (natural level)

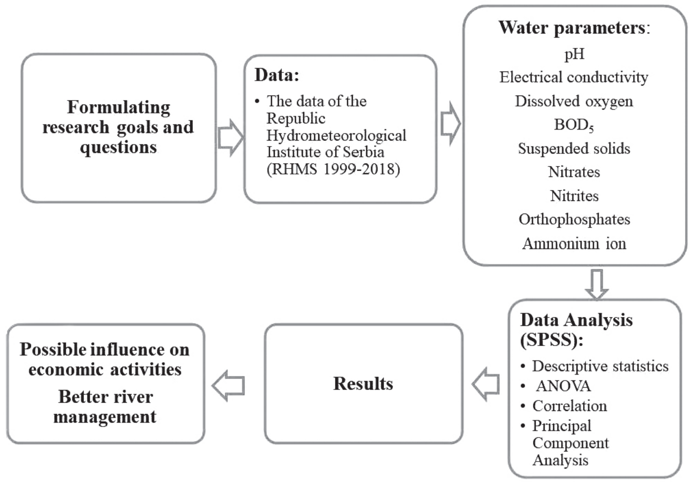

Fig. 2 – Conceptual framework of the water quality evaluation. Source: created by the authors.

used to determine statistically significant differences between certain groups of data (Obradović et al. 2020). The results of the F test can only confirm the statistical significance of the differences between the groups with the lowest and highest arithmetic means (Leščešen et al. 2015).

Descriptive statistical analysis was applied to determine average, maximum and minimum values on selected profiles and time series. The analysis of the dependent variables and the independent variables (annual and monthly values) was done using One-factor ANOVA. Pearsons correlation was applied to establish the variables with significant differences (Pantelić et al. 2022).

Principal component analysis (PCA) has the ability to identify and eliminate redundant data from results. By applying PCA, the amount of available data is reduced, and as a result different numbers of new variables are obtained, the so called main components (principal components, PC). The main component, PC, is in fact a linear combination of original variables (Vastag et al. 2013). The following factor loading criteria were applied in the paper based on earlier research (Liu, Lin, Kuo 2003): a factor loading value of 0.75 to 0.5 indicates a "medium" correlation, while a factor loading value of > 0.75 is regarded to be a "high" correlation. A substantial eigenvalue is one that is equal to or larger than 1, according to the research of Varol and Sen (2009), which served as the foundation of this usage. When choosing the number of factors, the Kaiser's criterion was applied, which retains only those factors that have characteristic values greater than 1, as well as the scree-test, which is a graphical representation of the eigenvalues of all components and suggests that in those components that significantly (visually) differ from the others in the scope of the variance are retained in the analysis.

Figure 2 shows the proposed research workflow and contains several main components such as: collected data, selected physicochemical parameters, applied methodological procedures, presented results and possible influence on some economic activites.

4. Results

The mean values of ten parameters for the analyzed twenty-year interval (1999–2018), as well as the results of the ANOVA test for SP1 (Bezdan), SP2 (Bogojevo) and SP3 (Novi Sad) are shown in Figure 3. Statistically significant differences on anual basis are observed in the parameters EC, BOD_5, NO_2 and PO_4, while in the other analyzed parameters statistical significance is not present. Mean annual water temperature and pH values are relatively uniform and do not show statistically significant differences on the profiles (SP1–SP3). The measured pH values are closer to the upper limit value (6.5–8.5), which indicates an increased alkalinity of the water. Mean values of EC on all profiles are statistically significant ($p < 0.01$ or $p < 0.05$). The electrical conductivity values are below the threshold value for the II class of water quality and do not exceed 1.000 µS/cm. At all measurement points, mean DO values do not show differences with statistical significance. Dissolved oxygen values are annually above the limit values for the II quality class. The trend lines show a slight increase in the mean values of water temperature, pH, EC and DO. Differences in BOD_5 values are statistically significant at the annual level for all profiles. Mean values of BOD_5 are within the defined standards for class II (5 mg/l). BOD_5 shows a downward trend, which indicates that the intensity of pollution of organic origin in the water of the Danube is decreasing over time. Suspended solids and nitrates show fairly uniform average values on the analyzed profiles, without statistical significance. Limit values of SS are higher than the permitted values (25 mg/l) for a number of years on profiles SP1–SP3. Nitrate values on all profiles do not deviate from the limit values for class II (3 mg/l). The content of dissolved substances in SP Bezdan shows a slight upward trend, while in SP Bogojevo and SP Novi Sad there is a downward trend. This is contrary to the expected results of the trend, since Gornje Podunavlje Special Nature Reserve is located in the sector between SP Bezdan and SP Bogojevo, a huge wet area with significant production of suspended matter. Nitrate content on the Bezdan, Bogojevo and Novi Sad profiles shows a slight downward trend. There are statistically significant differences in the nitrite content of the analyzed profiles. However, there are no deviations from the permitted limit values (< 0.03 mg/l). For this parameter too, a downward trend of concentrations is present on all profiles. For orthophosphate content, ANOVA did not determine statistically significant differences in mean values; also, the values correspond to

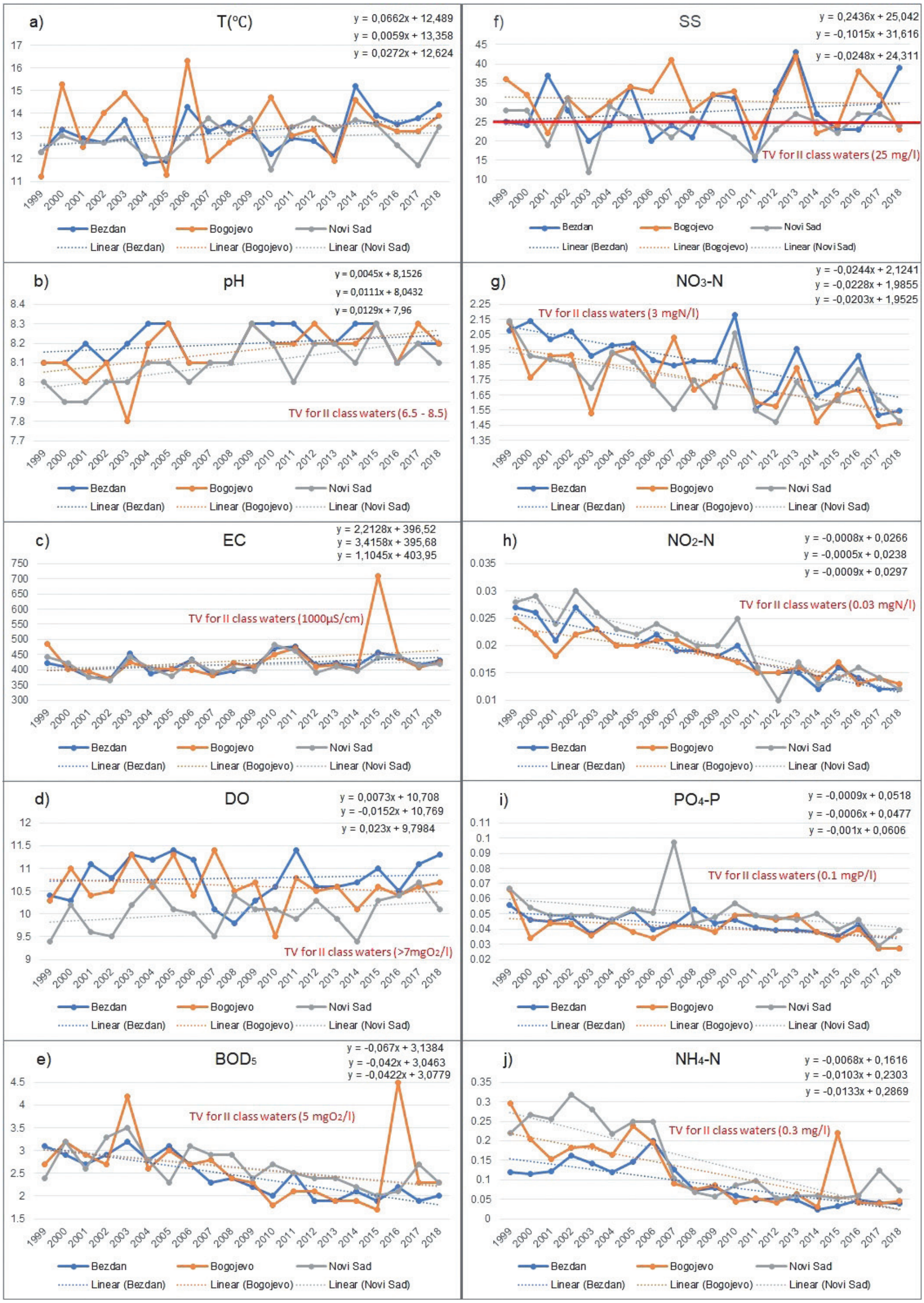

Fig. 3 – Mean values of water quality parameters for SP1 (Bezdan), SP2 (Bogojevo) and SP3 (Novi Sad) and ANOVA results per year. *Source:* created by the authors based on data analysis in SPSS 25.0.

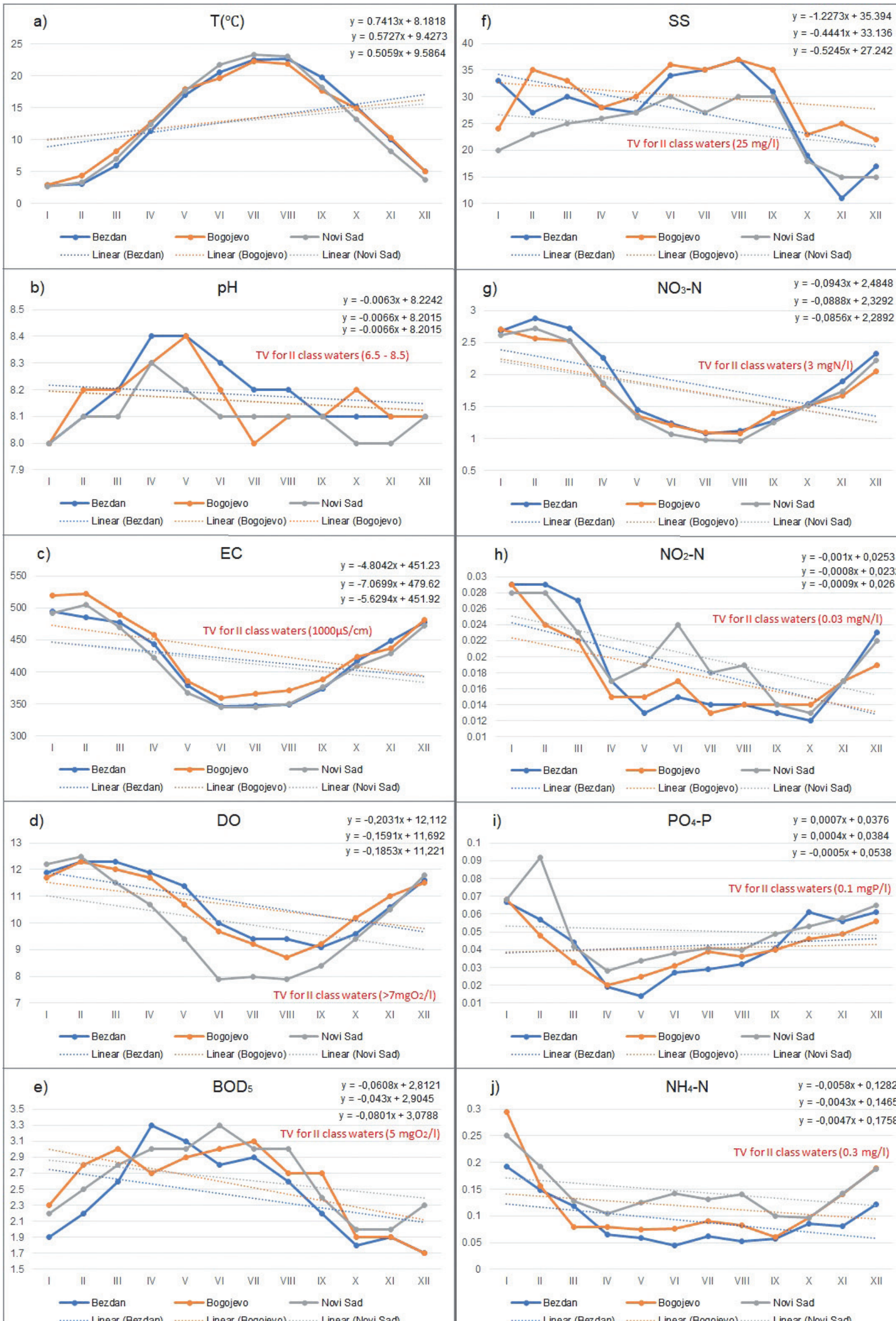

Fig. 4 – Mean values of water quality parameters for SP1 (Bezdan), SP2 (Bogojevo) and SP3 (Novi Sad) and ANOVA results per month. *Source:* created by the authors based on data analysis in SPSS 25.0.

the limit values for class II surface waters (< 0.1 mg/l); the content of PO_4-P shows a downward trend. Ammonium ion concentrations on all profiles show statistically significant values between the mean values ($p < 0.01$). As with the previous parameters, NH_4-N values do not exceed the permitted values (0.3 mg/l). During the analyzed period, ammonium ion values show a pronounced downward trend based on the trend equation.

The extreme annual values of the parameters show certain similarities on the analyzed profiles (Figure 3). Thus, the pH value shows the minimum annual values on the profile of Bogojevo and Novi Sad (2001). Minimum EC values were recorded in 2002 on the Bezdan, Bogojevo and Novi Sad profiles. The maximum DO values were recorded in Bezdan and Bogojevo in 2005. The maximum BOD_5 values were recorded in Bezdan and Novi Sad in 2003, while the minimum values were achieved in all profiles during 2015. The maximum SS values were detected in Bezdan and Bogojevo in 2013, while the annual minimums were achieved in 2011 on the same profiles. The maximum values of NO_3-N were determined in Bogojevo and Novi Sad (1999). In 1999, the NO_2-N and PO_4-P content showed maximum values on the Bezdan and Bogojevo. Minimum concentrations of PO_4-P were determined on all profiles during 2017. NH_4-N content reached maximum values on the Bezdan and Novi Sad during 2002.

The highest mean values of T, pH, BOD_5 and SS were registered during the spring and summer, while the maximum values of EC, DO, NO_3-N, NO_2-N, PO_4-P and NH_4-N were detected in the autumn and winter (Figure 4).

The results show that the average monthly pH values are within the permissible limits (6.5–8.5), closer to the upper limit, which indicates increased alkalinity of the water, especially in the spring. Average monthly values of electrical conductivity are quite uniform and do not show deviations from the permitted values. An unusual circumstance is the fact that the electrical conductivity values are slightly lower from May to September. Dissolved oxygen concentrations are far above the threshold values for water quality II class during all months, especially in the winter, which indicates the good quality of the Danube in Bačka. The monthly values of BOD_5 are fairly uniform and do not exceed the threshold value of 5 mg/l. In the spring and summer, slightly higher values are registered. Suspended solids on a monthly basis show excesses of the permitted limit values for the II quality class. In the case of nitrates, nitrites, orthophosphates and ammonium ions, during all months the values are lower than the permitted limit values. The trend lines show a slight to moderate decrease in the mean values of pH, EC, DO, BOD_5, SS, NO_3-N, NO_2-N, NH_4-N. The mean values of water temperature show a moderate increase. The trends of PO_4-P are not equally distributed. Bezdan and Bogojevo profiles shows a slight increase trend, while the Novi Sad profile shows a slight downward trend. Analysis of mean monthly values of water quality parameters on the Bezdan and Novi Sad profiles (SP1 and SP3) shows statistical significance

Table 2 – Summarized ANOVA results on a monthly basis for analyzed profiles

Profile		T (°C)	pH	EC (µS/cm)	DO (mg/)]	BOD_5 (mg/l)	SS (mg/l)	NO_3-N (mg/l)	NO_2-N (mg/l)	PO_4-P (mg/l)	NH_4-N (mg/l)
SP1	*F*	186.01	7.306	33.383	13.986	5.338	3.889	62.235	15.111	13.8	6.501
	p	0.000*	0.000*	0.000*	0.000*	0.000*	0.000*	0.000*	0.000*	0.000*	0.000*
SP2	*F*	56.64	1.75	6.89	8.318	2.558	1.736	32.569	9.241	9.478	5.295
	p	0.000*	0.065	0.000*	0.000*	0.005*	0.068	0.000*	0.000*	0.000*	0.000*
SP3	*F*	286.621	3.666	35.681	61.675	6.492	3.258	65.939	6.443	3.201	2.917
	p	0.000*	0.000*	0.000*	0.000*	0.000*	0.000*	0.000*	0.000*	0.000*	0.001*

Source: created by the authors based on data analysis in SPSS v25.0. Note: *p < 0,01 or p < 0,05; SP1 – Bezdan; SP2 – Bogojevo; SP3 – Novi Sad.

Table 3 – Pearson correlation analysis between physicochemical parameters

	T (°C)	pH	EC (µS/cm)	DO (mg/l)	BOD_5 (mg/l)	SS (mg/l)	NO_3-N (mg/l)	NO_2-N (mg/l)	PO_4-P] (mg/l)	NH_4-N (mg/l)
T	1									
pH	0.116**	1								
EC	-0.662**	0.021	1							
DO	-0.624**	0.342**	0.473**	1						
BOD_5	0.272**	0.148**	-0.204**	0.118**	1					
SS	0.199**	0.009	-0.225**	-0.149**	0.082*	1				
NO_3-N	-0.853**	-0.158**	0.586**	0.510**	-0.205**	-0.099**	1			
NO_2-N	-0.463**	-0.292**	0.253**	0.191**	0.037	-0.006	0.594**	1		
PO_4-P	-0.341**	-0.320**	0.175**	-0.017	-0.271**	-0.110**	0.360**	0.324**	1	
NH_4-N	-0.317**	-0.309**	0.223**	0.033	0.068	-0.097*	0.346**	0.574**	0.231**	1

Source: Created by the authors based on data analysis in SPSS v25.0. *Note:* *Correlation is significant at the 0.05 level; **Correlation is significant at the 0.01 level.

for all parameters, while on the Bogojevo profile (SP2) statistical significance was not established for two parameters, pH and SS (Table 2).

Pearson's correlation coefficients shown in the matrix (Table 3) represent the result of statistical analysis of the relationship between ten physicochemical parameters of water quality for the Danube in Bačka. A moderate negative correlation was recorded in the relationship between water temperature and electrical conductivity ($r = -0.662$), dissolved oxygen ($r = -0.624$) and especially nitrate content ($r = -0.853$). A moderately strong positive correlation is present between electrical conductivity and nitrate ($r = 0.586$), dissolved oxygen and nitrate ($r = 0.510$), nitrate and nitrite ($r = 0.594$), and nitrite and ammonium ions ($r = 0.574$).

Water quality parameters for all three profiles on the Danube in its course through Bačka were subjected to principal component analysis (PCA). Before

Table 4 – Factor score coefficient matrix and correlation of variables and factors for PCA with oblimin rotation for scale items water quality parameters.

Danube river			
Water quality parameters	Factor loadings		
	F1	F2	F3
T (°C)	−0.912		
NO_3-N (mg/l)	0.902		
EC (μS/cm)	0.717		
NO_2-N (mg/l)	0.676		
NH_4-N (mg/l)	0.522		
PO_4-P (mg/l)	0.484		
pH		0.778	
DO (mg/l)		0.696	
BOD_5 (mg/l)			0.814
SS			0.286
Eigenvalues	3.60	1.78	1.29
% variances by components	36.03	17.83	12.92
Total % variance	36.03	53.86	66.78

Note: factor load value greater than 0.75 – connection "high"; factor load value from 0.75–0.5 – connection "medium"; factor load value less than 0.5 – connection "low". *Source:* Created by the authors based on data analysis in SPSS v25.0.

conducting PCA, the suitability of the data for factor analysis was assessed. An examination of the correlation matrix revealed a large number of coefficients with values of 0.3 and higher. The value of the Kaiser-Meyer-Oklin indicator is 0.730, which corresponds to the recommended value of > 0.5 (Barakat et al. 2016). Also, Bartlett's specificity test reached statistical significance ($p = 0.000$), which indicates the factorability of the correlation matrix. PCA revealed the presence of three factors with values above 1, which explained 36.03%, 17.83%, and 12.92% of the variance (Table 4). An examination of the curve diagram revealed the existence of a clear breaking point after the third component or factor. Based on Kettel's criteria, it was decided to keep all three factors for further research. This was supported by the results of the parallel analysis, with three factors whose characteristic values exceeded the corresponding threshold values obtained using an equally large random number matrix (10 quality parameters × 1,332 samples). The three-component solution explained a total of 66.78% of the variance. To aid in the interpretation of these three factors, an oblimin rotation was also performed. The rotated solution revealed the existence of a simple structure, where all three factors have large factor weights of individual parameters.

The first factor contributes 36.03% of the total variability and is most consistent with the parameters T, NO_3-N, EC, NO_2-N and NH_4-N. The first factor has a high negative loading for T (−0.912) and a high positive loading for NO_3-N (0.902) and EC (0.717). Medium loading is for NO_2-N (0.676) and NH_4-N (0.522) (Table 4). The first factor is related to the eutrophication processes. The second factor contributes 17.83% to the total variability. It shows a high positive loading for pH value (0.778) and a medium loading for DO (0.696). This is ecological factor that determine many physical, chemical and biological processes in the environment of aquatic ecosystems (Table 4). The third factor contributes 12.92% of the total variability. It is positively associated with the parameter BOD_5 (0.814), and related with concentrated sources of pollution (Table 4).

5. Discussion

The data that were analyzed show that the Danube flow via Bačka may be impacted by both concentrated and diffuse sources of pollution. Among the diffuse pollutants, the following stand out: soil contamination of chemical origin due to excessive use of artificial fertilizers and pesticides in agriculture, sanitary and "wild" (unregulated) landfills of municipal and industrial waste, acid rain, the impact of traffic (Stojanović, Pavić, Mesaroš 2014; Vujović 2014). The largest polluters in the Danube sector are industrial plants, whose wastewater emissions operate as a concentration of materials for an area with enhanced pollution, according to a Bačka analysis of concentrated sources of pollution (Radišić 2018). First of al., there are (Figure 5): (a) refineries (Novi Sad), (b) food industry (oil industry "Vital", meat industry "Karneks", sugar factory "Bačka" – Vrbas; meat industry "Neoplanta" – Novi Sad; sugar factory "Crvenka" – Crvenka; AIK "Bačka Topola" in Bačka Topola), (c) rebar factory "Istra" in Kula (Puzović, Radovanović-Jovin 2011).

Apart from underground aquifers, Bačka's water supply is partially oriented to water withdrawals from the Danube alluvium. Current water supply systems are, according to the presented results, potentially threatened by increased concentrations of suspended substances. In addition, the summary results of SS show exceeding values in Bezdan and Bogojevo, while in the lower part of the stream (Novi Sad), no exceeding of permitted values was recorded. The displayed values lead to increased turbidity of the river waters of the Danube, which, in addition to the deterioration of water quality, is also the cause of the high cost of water purification treatment (Kukučka, Kukučka 2013).

The multifunctional Danube-Tisa-Danube Hydrosystem (DTD) is of particular importance in the irrigation of agricultural crops in Vojvodina. The basic canal network of this hydrosystem enables the collection of water for the irrigation of 210,000 ha of agricultural land in Bačka (Đurić, Popin, Erdelji-Stričević 2011). In general, the quality of the Danube water used for irrigation purposes is at a satisfactory level in terms of annual and monthly values. A possible problem is the excess of suspended substances. From a seasonal point of view, exceedances of the permitted values of the content of suspended matter are most common

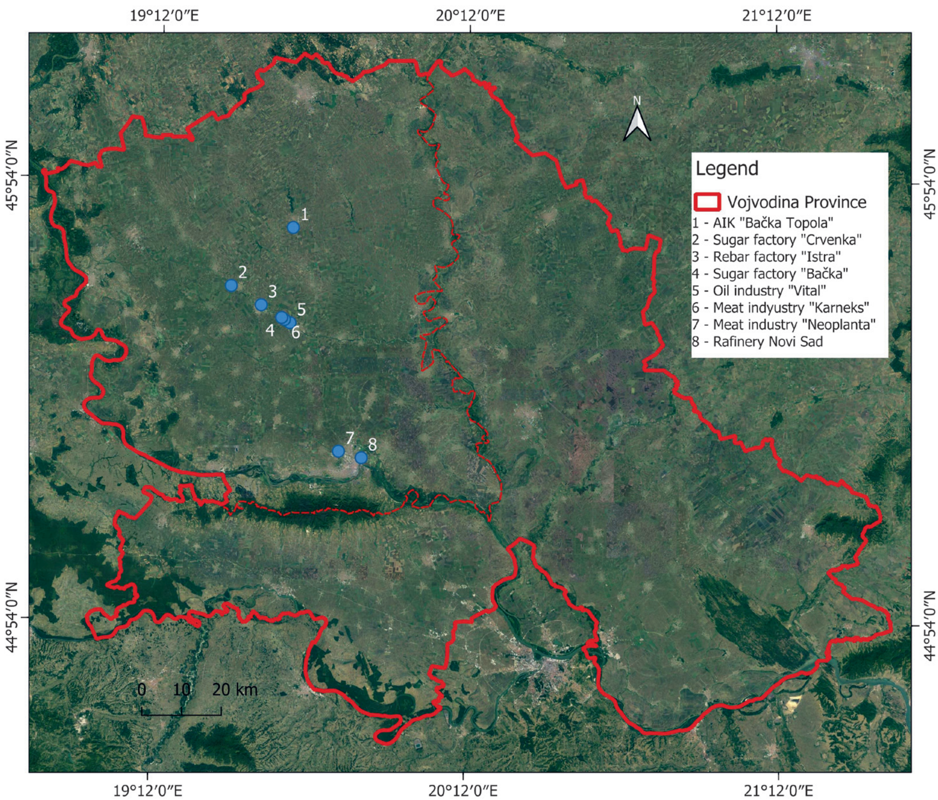

Fig. 5 – Spatial distribution of pollution sources in Bačka, Vojvodina Province. Source: visualized by the authors.

during the spring and summer months. The mentioned circumstances can be unfavorable from the aspect of irrigation because it is about periodic pollution and poorer water quality in the warmer half of the year; during the spring and summer months, irrigation is necessary for sustainable agricultural production, so it is limited by the deterioration of the water quality of the Danube. Nitrogen and phosphorus compounds in water can originate from atmospheric precipitation, plant and animal waste, industrial waste water, use of nitrogen and phosphorus fertilizers, waste sewage water etc. In natural conditions, these parameters should be positively correlated with water and air temperature. However, the consequence of negative anthropogenic influences and excessive discharge of waste industrial and sewage water, as well as intensive washing from agricultural land leads to the fact that the increase in the mentioned parameters is also present in the period when the temperature drops, that is, in the colder period of the year. What justifies the results of the obtained correlation in this research.

Drainage of excess internal waters, in the territory of Vojvodina, has a long tradition and is one of the basic activities aimed at regulating the water-air regime of the soil (Đurić, Popin, Erdelji-Stričević 2011). In the Danube valley, floods are predisposed by precipitation, but also by the coincidence of the passage of a flood wave on the main tributaries. The water regime of the Danube indicates that the highest water levels on the profiles through Bačka occur in the summer months (Jakovljević 2015). Exceeded values of suspended solids on the Danube, especially if they correspond to the highest water levels during the spring and summer months, may result in the contamination of agricultural areas and impact soil quality. By draining contaminated excess water, it is impossible to completely eliminate pollutants from the fertile soil layer, so this is a limiting factor in agricultural production, while the favorable circumstance is the fact that the mentioned trends are of a periodic nature (in the warmer period of the year).

Reliance on agriculture as a traditional activity in the area of Vojvodina, including Bačka, conditioned the development of branches of the food industry (Stojanović, Janjušević 2018). On certain profiles or even the entire course of the Danube, due to the increased concentration of suspended solids, the quality of the water is not suitable for the needs of industry, especially the food sector. Water of poorer quality was registered in the summer months, so the supply of water to the industry is difficult without appropriate purification treatments. The food industry is specific as it requires the use of high quality water in its production processes. However, the quality of the Danube water in the part of the flow through Bačka shows satisfactory results for the use of this water in other industrial branches (textile, mechanical, chemical).

As part of the Pan-European Corridor VII, the Danube with its tributaries belongs to the Danube Navigation System and is a waterway of traffic and transport importance at the national and regional level (Čolić et al. 2013). In general, for the needs of navigation, the water quality is at a satisfactory level. Potential limiting factors are represented by occasional exceedances of suspended matter values. Exceeded values of suspended solids in certain sectors as well as in the entire course of the Danube can make navigation conditions difficult, especially in the summer half of the year.

The Danube river provides favorable conditions for sport and recreational fishing, and due to its physical-chemical and biological characteristics of the water, it is extremely favorable for fishing. Out of a total of 94 species of fish found on the territory of Serbia, as many as 70 species inhabit the Danube river (Puzović, Radovanović-Jovin 2011). In general, the satisfactory water quality of the Danube is not a limiting factor for sustainable fishing. Among them, the concentrated sources of pollution on the Danube with the emission of wastewater originating from industry, from large livestock farms and from agricultural areas represent a potential danger for the survival of ichthyofauna. The average annual and monthly values of dissolved oxygen on the Danube are above the limit value for the II quality class. This indicates an optimal air regime, which greatly affects the ichthyofauna population.

The most attractive tourist river in Vojvodina and Serbia is the Danube, which is navigable along the entire length of its course through Vojvodina (Dragin, Jovičić, Lukić 2010). From the aspect of water quality, conditions are favorable for the development of nautical tourism, while the unit "threat" is represented by the increased content of suspended materials in certain sectors of the Danube, especially in the warm half of the year, which can be held in the second half of the year. To a certain extent, this can have an undesirable effect on the nautical tourism of the Danube, because the summer is the period of the year when the conditions for tourism are very favorable. Important protected natural resources (Gornje Podunavlje SNR and Karađorđevo SNR) are located in the alluvial plains of the Danube, so the activity of nature protection appears as a significant potential danger (Stojanović, Pavić, Mesaroš 2008). The mentioned protected natural areas are centers of endemic and relict biodiversity and are important in the development and promotion of ecotourism. The deterministic results indicate that the manifested "anthropogenic pressures" are not significantly pronounced and do not impair the quality of the Danube waters. Bearing in mind the satisfactory ecological status of the Danube, there is no "threat" to damage biodiversity, which fully justifies the possibility of intensive development of ecotourism in protected areas (Obradović et al. 2020). However, occasional exceedances of the content of suspended solids in the Danube can adversely affect aquatic ecosystems. Namely, a higher concentration of SS affects the increased turbidity of the water, which makes it difficult or even impossible for aquatic organisms to access food, which can ultimately lead to large-scale fish kills. Stojanović, Pavić, Mesaroš (2014) point out that one of the types of tourist activity in the protected natural resources of Vojvodina and Bačka is sport fishing, so this segment of the ecotourism offer is threatened.

It is difficult to identify identical water pollution parameters[1] and its changes on regional scale, but certain similarities exist according to JDS 1 and JDS2 (ICPDR 2002, ICPDR 2008). Variations in water temperature during the JDS1 and JDS2 showed similarities along the Upper Danube reach. Higher fluctuations occurred in the Middle Danube reach and particularly downstream of the Iron Gate during the JDS2. This was the result of changes in weather conditions, as well as the increase in water discharge. It is notable that the fluctuations in pH values were more significant than in the case of DO, particularly during the JDS2. This could be the effect of higher fluctuations in water temperature and discharge. The significant

[1] On the basis of JDS1 and JDS2 reports, concentration of BOD5 were not sampled and statistically observed.

decrease of pH values were observed in the area of the Iron Gate, which might be the result of increasing biodegradation activities. EC values during the JDS1 and JDS2 revealed very similar trends. In the Upper Danube, the low salt content of the Inn significantly influenced the downstream reach of the Danube, due to their similar flow values. In the Lower Danube, even though some tributaries had relatively higher conductivity values at the confluence, no significant influence on the downstream Danube stretch was recorded. During the JDS1, a significant increase in DO concentration at the beginning of the Middle Danube resulted from algal blooming; a significant increase in primary productivity and the likely related decomposition of organic matter downstream to the Iron Gate. SS showed strong variations in all sectors of Danube river basin. For example, values of SS are low in the Upper Danube. Exception is the confluence of Danube with river Morava (near Bratislava) where concentration of SS rapidly increases. In the Middle Danube SS remains low to moderate. Along the Lower Danube, SS steadily increase towards the outflow to the Black Sea. The increase is mainly due to inorganic suspended solids washed in from the large tributaries. In the Danube main stream during the JDS2, the highest concentrations of NO_3-N were measured upstream of the confluence of the Inn. Downstream of the Inn, the nitrate concentration decreased and remained relatively constant downstream of the Iron Gate. The NO_2-N concentration had a decreasing character in the Upper Danube. The middle reach was characterised by a uniform distribution, followed by a peak in the Iron Gate. A significant decrease in the PO_4-P concentrations occurred downstream of the Inn confluence. In the Middle Danube, a slight increase was observed, followed by a decreasing until the minimum level (at the confluence of the Tisa). In the backwaters of the Iron Gate, slightly increasing orthophosphate concentrations were measured, and levels basically remained the same up to the Danube Delta. At most of the sampling sites in the Danube, the concentrations of NH_4-N were near to the limit values except for a slight increase in the backwater of the Iron Gate. Higher concentrations were measured in the dammed Danube arm, reaching an extreme high value caused by the secondary discharge of untreated municipal wastewater from the Bucharest sewage system.

The pollution along the DRB in Europe is caused mainly by the following factors (ICPDR 2005, Gasparotti 2014): (a) point sources (municipal, industrial and agricultural); (b) diffuse sources (agricultural, agglomerations); (c) effects of modifying the flow regime through regulation and (d) morphological alteration. In general, The JDS2 found that about 40% of the investigated Danube indicated a satisfactory condition, meaning that there are still many areas with generally healthy ecological conditions – a status that is generally more positive than earlier perceived. The situation in the Lower Danube is better than in the Upper part. However, another third of the Danube is strongly altered by human actions with many areas requiring attention (ICDPR 2007c).

Nearly 72% of all drinking water consumed in the DRB is produced from groundwater sources, serving an overall population of about 59 million people. Groundwater also provides much-needed water for agricultural irrigation, and it is an important resource for other industrial activities (ICDPR 2015). Therefore, exceeded values of SS in some sectors (e.g. Bratislava in the Upper Danube, some sectors in the Lower Danube), NO_3-N (near Inn in the Upper Danube), NO_2-N (Iron Gate), PO_4-P and NH_4-N (Iron Gate in the Middle Danube and the Romanian part of the Middle Danube).

The extensive irrigation systems are characteristic for the large agricultural areas in the Middle and Lower Danube Basin, e.g. Hungary and Romania, where the infrastructure has been planned for large scale irrigation application. However, although all countries extract irrigation water from the common Danube water resources, data is largely available only on the national level, therefore no comprehensive and homogeneous data set is available on the irrigation in the DRB (Dogaru et al. 2019). According to the results, the occasional increasing of SS, NO_2-N, PO_4-P and NH_4-N in some sectors of the Middle and Lower Danube can affect the irrigation sustainability.

Agriculture is an important component of the economy in Danube countries since the geographical and climatic conditions in large parts of the DRB are favourable for agriculture and related industry. More than 50% of the basin territory are under agricultural cultivation. In the Western regions agriculture plays a key role as local supplier of commodities that are further transformed into food. In the Eastern regions agriculture is one of the most important employers in rural regions (ICPDR 2021). As in the case of irrigation, identical parameters can periodically affect the water quality for the needs of agriculture and related activities. Industry, after services, represent a major economic sector throughout the Danube region and its participation in GDP varies from 31% (Slovakia) to 42% (Romania) (Danube Regional Project 2007). Generally, based on the JDS2 results, most of the DRB has the water quality of satisfactory level for most sectors of industry.

The Danube is an international river of great importance and the usage of this waterway is dominant for the transport of goods and people. Danube transport is influenced by two key factors on the transport: (a) the navigation conditions, depending on the environmental conditions and (b) waterway maintenance. The traffic by ships on the Danube (2001–2020) was relatively uniform and stable, while the traffic of goods showed the increasing trend. The decreasing trend was noticed during the 2019 and especially during 2020, caused by the COVID-19 pandemic (Chirosca, Rusu 2021). The increased values of SS in the Lower Danube make navigation conditions difficult which is more expressed in combination with low waters during the summer season. The increasing trends of nitrites, orthophosphates and ammonium ions in the Lower Danube can cause eutrophication which is also a limiting factor for navigation and transport.

More than 70 species of freshwater fish inhabit the Danube along its entire course. Although fish stocks have declined and species became endangered or even extinct in the last decades, fish are still a subject of economic importance. Besides this importance, the fish population is potentially a good indicator of human pressures, in particular in the form of hydromorphological alterations. During the JDS2, the results show that hydromorphological alteration is the main pressure in the upper section, while the water quality is a prevailing pressure in the middle and lower sections. Navigation also seems to have a negative impact on fish populations, especially in the upper part of the DRB. Hydromorphological alterations are recognised by the ICPDR as one of four basin-wide significant water management issues. The most significant alterations were categorised into: longitudinal continuity interruptions (49 base-load hydroelectric power dams are situated in the Upper Danube and 3 major barrages in the Middle Danube (Gabcikovo, Iron Gate 1 and 2); lateral connectivity interruptions (loss of floodplains, bank reinforcements) and hydrological alterations (water abstraction of residual water; Schiemer et al. 2004, ICDPR 2008). Also, one of the major environmental problem in term of the fishery in the Middle Danube is related to blocking of traditional fish migration routes by dams and hydro-power plants (not equipped with functioning fish-ladders or passages) which lead to decline of particularly high-quality fish species. For example, it was reported that after the construction of Djerdap I and II hydroelectric power plant the catch of the *Acipenseridae* dropped from more than 12 tons per year to less than 5.5 tons per year (ICDPR 1999).

The Danube Corridor is one of the most popular river cruise routes in the world. Passenger cruises traffic intensity on the Danube (2012–2017) showed increasing trends of passengers. These are suitable conditions for nautical tourism. in the structure of passenger traffic on cruise voyages on the Danube, the Upper DRB holds a dominant share of 82%, while the remaining 18% refers to the Middle and Lower DRB. The reason for this lies in the fact that the Upper DRB stretches through the territories of economically developed European countries such as Germany and Austria, which also have the highest concentration of ports and associated port facilities for passenger traffic and a wide range of tourism supply side (Poletan Jugović, Komadina, Sirotić 2020). Therefore, the affirmation and perspective of passenger flows on cruise voyages on the Danube is reflected in their intensification, especially in the Lower and Upper DRB. Based on the results, the increasing trends of SS in the Lower DRB may occasionally affect the sustainablity of the nautical tourism and reduce even more passenger traffic in this sector of DRB.

Due to its large area and very diverse habitats – gravel islands on the Upper DNB, significant areas of forest floodplain, extended wetlands on the Lower DRB – the Danube provides the right living conditions in areas of high landscape and biodiversity for a large number of different species. Along its course there are some 230 of the DRB's 2,860 Natura 2000 sites, an ecological network of internationally important protected areas in the territory of the EU. Over 2,000 plant species and 5,000 animal species live in or by the waters of the Danube, a habitat which hosts about 2,000 vascular plants, over 40 mammals, approximately 100 fish species. At 6,750 km², the delta of the Danube River is one of the world's largest wetlands (and Europe's largest remaining natural wetland) featuring rare fauna and flora, as well as 30 different types of ecosystem. Located in the territories of Romania and Ukraine, it became a UNESCO World Heritage Site in 1991 (ICDPR 2009). The large biodiversity and numerous protected areas enable the development of ecotourism. However, the environmental sustainability of the Lower DRB may be endangered from the nutrient pollution. It is caused by significant releases of orthophosphates and ammonium ions into the aquatic environment of the Lower DRB.

6. Conclusions

Based on the summarized results of the ANOVA analysis, it can be concluded that the water quality for the Danube sector in Bačka is at a satisfactory level and is mostly within the defined standards for the II quality class. Average annual and monthly values of Danube water quality parameters in Vojvodina indicate the following: (a) the content of dissolved oxygen at the profile on the Danube shows values that are above the limit values for the II credit class, which indicates good aeration, i.e. the supply of water with oxygen is important for the functioning of aquatic organisms; (b) annual and monthly values of the content of suspended solids show exceeding the limit values in all analyzed profiles on the Danube; particularly high values were expressed on the analyzed profiles in the summer half of the year (above the permitted values for class II). Since the Danube is on the Pannonian sector of the flow of plain character, elevated concentrations of SS are expected and justified; (c) summary values for the flow of the Danube through Bačka indicate that all parameters, with the exception of suspended solids, are within the permitted limits.

Based on the trend assessment of mean annual values, a slight increase of water temperature, pH, EC and DO on most of profiles were detected. In the case of BOD_5, SS, NO_3-N, NO_2-N, PO_4-P and NH_4-N slight decreacing trends were observed. The evaluation of mean monthly values showed a slight to moderate decrease of observed parameters (pH, EC, DO, BOD_5, SS, NO_3-N, NO_2-N, NH_4-N). Exceptions were recorded on the montly basis in the case of water temperature (moderate increase) and orthophosphates (Bezdan and Bogojevo showed a slight increase, but on Novi Sad profile a slight decreasing trend was detected).

Based on the analysis of the main components, three factors have been identified that affect the quality of the Danube water. The first factor (F1) contains five parameters, of which nitrates affect organic pollution, while the NO_2-N and NH_4-N are discharged from the industrial, domestic wastewater or livestock farms. Generally, the first factor has a favorable effect on eutrophication. The second factor (F2) indicates the influence of pH and DO in term of enviromental demands. The third factor (F3) can be correlated with concentrated sources of pollution (e.g. sewage systems from households, urban areas, industrial infrastructure).

The limited data on the sources of diffuse pollution of the Danube flow through Bačka leave many doubts. It is indisputable that due to intensive agricultural production followed by the irrational use of mineral fertilizers and pesticides, there is a marked leaching of chemical substances into surface waters. The use of artificial fertilizers based on nitrogen and phosphate is the cause of eutrophication in certain sectors of the Danube. A potentially threatening factor is the increased value of suspended matter, which, especially in the warmer half of the year, limits activities such as water supply, irrigation and drainage, food industry, navigation conditions, types of tourism (nautical and ecotourism). On the other hand, optimal conditions for dissolved oxygen content have a favorable effect on activities such as fishing.

The paper shows the importance from the aspect of statistical evaluation of extensive databases in the sense of quantification of information on surface water quality. The results can represent a solid basis for planning activities in the future protection of water resources of the Danube, the basis of regional development and spatial planning policy, informing the public about water quality and providing recommendations for the use of available water resources.

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