Carpathian Journal of Earth and Environmental Sciences, September 2011, Vol. 6, No. 2, p. 269 - 277

# ASSESSMENT OF POLLUTING EFFECTS AND SURFACE WATER QUALITY USING WATER POLLUTION INDEX: A CASE STUDY OF HYDRO – SYSTEM DANUBE – TISA – DANUBE, SERBIA

**Ana MILANOVIĆ, Dragana MILIJAŠEVIĆ & Jovana BRANKOV**
*Geographical Institute "Jovan Cvijić" Serbian Academy of Science and Arts*
*Đure Jakšić Street 9/III, 11000 Belgrade, Serbia*
*e-mail: a.milanovic@gi.sanu.ac.rs, d.milijasevic@gi.sanu.ac.rs, j.brankov@gi.sanu.ac.rs,*

**Abstract:** The Hydro-system Danube-Tisa-Danube stretches along 12 700 km$^2$ in the North of Serbia. In view of the multiple role of the canals (drainage, irrigation, water supply of settlements and industry, navigation, fishing, etc.), there are numerous pollution sources that influence the water quality. Using the data of the Republic Hydrometeorological Service of Serbia, the paper analyzed the water pollution levels in the canals using the combined physical-chemical WPI index (water pollution index). The samples were taken monthly from a total of 9 stations between 2004 and 2009. The following parameters were taken into consideration: dissolved $O_2$, $O_2$ saturation, pH, suspended sediments, biological oxygen demand ($BOD_5$), chemical oxygen demand ($COD_{Mn}$), nitrites, ammonium, saprobic index, metals (Fe, Mn, Ni, Hg), sulphates and coliform germs. The mean WPI values are calculated for the respective period based on the comparison of mean annual values of parameters and defined standard values for the I class of water quality (according to the Rules of Procedure on the Hygienic Quality of Water of the Republic of Serbia). The research has shown a decreasing trend in pollution since 2007 as a result of performed canal water cleansing. The analysis of parameters ($BOD_5$, ammonium, coliform germs) that have the greatest impact on the pollution confirmed the prevalence of organic pollution compared to the non-organic one, so that food industry, agriculture and sewage water feature as major polluters.

**Key words**: The Hydro-system Danube-Tisa-Danube, Veliki Bački canal, Water Pollution Index (WPI), water classes, biological oxygen demand ($BOD_5$), ammonium

## 1.INTRODUCTION

Numerous hydrological studies in the world have pointed to major ecological importance of surface waters so that as a result research of the sustainable water management has intensified. Certain studies in this segment refer to the quality and pollution of watercourses and they mostly rely on application of different mathematical-statistical methods. Lately, there is a growing number of analyses of the watercourses quality with certain statistical models such as: Cluster analysis (CA), Factor analysis (FA), Principal component analysis (PCA), Discriminant analysis (DA) (Vega, 1998; Guler, 2002; Simeonov, 2003; Kunwar, 2004; Heshan, 2005; Shrestha, 2006) or by defining the mathematical indices. Authors most often use WQI (water quality index) (Sanches et al., 2007; Bordalo et al., 2006; Cude, 2001), WPI (water pollution index) (Lyulko et al., 2001), as well as RHS (river habitat survey) method for the classification and assessment of physical characteristics of running waters and determining the ecological status of river habitats (Raven et al., 2000, 2002, 2005; Erba, 2006; Milanović et al., 2006; Kamp, 2007; Urošev et al., 2009) as the most reliable indicator of the watercourses pollution.

Specific and complex changes of the water quality in Vojvodina rivers and canals emphasize the significance of applying none other but those index methods which enable the determination of common values that cover the quality as a whole. Thus, the water quality of the Danube course through Serbia was analysed by the WQI method (Veljković & Jovičić, 2007) as well as of other watercourses, including the canal network (Veljković et al., 2008). The WPI method also offers a way of meeting to this request, but also of determining the types and degrees of pollution. Therefore, in this paper the research of the pollution was based on the application of the WPI method.

The oldest melioration works in Vojvodina go back to the Roman age and mainly represented anti-flood protection. More extensive works on marsh drainage and canal construction were done during the times of Austria-Hungarian Empire in the 18th and the 19th century. Reconstruction, as well as addition of new canals were carried out in the 1958-76 period.

The Hydro-system Danube-Tisa-Danube has great economic significance for Serbia. It serves a multitude of purposes: drains the excess water during humid season, provides necessary water quantities for irrigation in dry season, supplies water to industry and some settlements around the main canal network, serves for navigation, fishing, etc. It enables the drainage of 760 000 ha and irrigation of 510 000 ha of land, but has been only partially used in practice. With the construction of this Hydro-system, Serbia got 664.1 km long good-quality navigable network. The navigable routes are designed to transport 2.8 million tons of goods annually (Gavrilović & Dukić, 2002). The Hydro-system Danube-Tisa-Danube was built with the aim of solving water supply problems of the population and industry in Vojvodina, since only small quantities of water can be obtained from the artesian wells. However, in view of the pollution levels, the canal water is not fit for use.

## 2. STUDY AREA

Vojvodina, situated in southern part of Pannonian basin, has large water resources in the surface waters of the rivers Danube, the Tamiš and the Tisa, as well as in the developed Hydro-system Danube-Tisa-Danube. The system of canals is located between 44°51' and 45°52' N and 18°51' and 21°17' E and stretches over some 12 700 km$^2$ between the Danube and the Tisa rivers, in the Vojvodina regions– Bačka and Banat (North Serbia). The total length of the canal is 929 km, including new and old canals and tributaries which were partly, or as a whole, integrated into the system of canals. There are 51 constructions (24 gates, 16 locks, 5 safety gates, 6 pump stations and 180 bridges) in the canal network. The main canal route starts at Bezdan in Bačka where a large feeding sluice-gate was built on the Danube left bank with 3 spillway planes, through which up to 60 m$^3$/s of water from the river flows into the canal by gravitation. From here, the canal goes in the direction of Prigrevica - Srpski Miletić - Savino Selo - Vrbas, entering Veliki Bački canal and leading to the Tisa river near Bečej. Downstream from Novi Bečej (62 km from the mouth into the Danube), the Tisa is dammed by a concrete dam 520 m long, with 7 spillways and ship lock. It held back the Tisa waters, raised its level by 6.67 m and formed a dike dam with a backwater up to Segedin. Behind this dike dam, which has the volume of 51 million m$^3$, the main canal drains 35-50 m$^3$/s of water. It runs off further in the direction of Klek-Botoš (where the canal intersects the River Tamiš)-Potporanj-Banatska Palanka, where the canal enters the Danube (Gavrilović & Dukić, 2002).

The largest and the most important watercourse in this region is the Danube, which flows through Serbia in the length of 588 km. By to its natural characteristics its flow can be divided into 3 different sectors: Pannonian, Đerdap and Pontic. In its Pannonian sector the Danube has an average river bed drop of 0.05 m/ km, the average water velocity of 3-4 km/h, and the average discharge of 3 500 m$^3$/s (Bjeljac et al., 2004). The regular measurements of the Republican Hydrometeorological Service of Serbia show that, according to the objective criteria the water quality of the Danube at the exit from Serbia is somewhat better than at the entrance. Such state is partly explained by the Đerdap reservoir, which works as a large catch basin.

The River Tisa (966 km long, 164 km long in Serbia) rises in Ukraine and is the largest left tributary of the Danube flowing through the Pannonian basin. It is critically polluted by organic substances from municipalities and urban settlements, nutrients from cattle farms and accidental wastewater discharges from industry and mining (Burnod-Requia, 2004; Shepherd & Csagoly, 2007). According to the bilateral agreement on the water quality of rivers leaving Hungary, both the Danube and the Tisa rivers should have II class quality water when entering Serbia, but this is rarely the case (Samsonová & Šarapatka, 2005). Also, the Tisa water quality has additionaly deteriorated in Serbia through the influence of industry, agro-technical measures, water management infrastructure and especially the canal network (Ocokoljić et al., 2009).

The River Tamiš (340 km long) rises in the northern part of the Romanian Carpathian Mountains, passes through Banat and flows into the Danube near Pančevo. It is one of the most polluted rivers in its entire course through Serbia (118 km). Its waters are overburdened with industrial sewage from both Romania and Serbia.

The River Begej is the largest left tributary of the Tisa in Serbia. The total length of the Begej is 244 km, out of which 168.5 km in Romania and 75 km in Serbia. From the biological viewpoint, the Begej is also ranked as one of the most polluted watercourses. The increased contents of organic substances in the Begej are the consequence of the discharge of unpurified industrial and faecal waste waters of Timisoara and Zrenjanin. Owing to a small discharge and negligible velocity rates, the waters of the Begej river have low self-purification capacity.

## 3. MATERIALS AND METHODS

Data of the Republic Hydrometeorological Service of Serbia on the quality of watercourses and canals in the period 2004-2009 were used for analysis in this paper. The research included identified profiles in the canal network of the Hydro-system Danube-Tisa-Danube at which systematic assessment of the water quality has been carried out (approximately once a month):

- route Vrbas-Bezdan (profiles Sombor, Vrbas I and Vrbas II);
- route Bečej-Bogojevo (profile Bačko Gradište);
- route Novi Sad-Savino Selo (profile Novi Sad);
- route Bački Petrovac-Karavukovo (profile Bački Petrovac);
- Jegrički canal (profile Žabalj I);
- Moravica (profile Vatin);
- Brzava (profile Markovićevo).

Location of Hydro-system study area and hydrological sample stations, which were used for analysis in this paper are presented in Fig. 1.

Since the quality assessment implies the determination of physical-chemical parameters of the canal waters, the following methods[1] were used by Republic Hydrometeorological Service of Serbia for such an analysis: for dissolved oxygen - SRPS H.Z1.135; for suspended sediments - 13.060.30 SRPS H.Z1.160; for pH value - SRPS H.Z1.111; for ammonium ion ($NH_4$-N)- SRPS ISO 5664; for nitrites ($NO_2$-N) - SRPS ISO 6777; for sulphates ($SO_4^-$)- APHA AWWA WEF 4500 - $SO_4$; for dissolved iron (Fe) and dissolved manganese (Mn)- dissolved APHA AWWA WEF 3111 B; for dissolved mercury (Hg)- EPA 245.1; for dissolved nickel (Ni) - dissolved APHA AWWA WEF 3113; for biological oxygen demand ($BOD_5$)- EPA 360.2; for chemical oxygen demand ($COD_{Mn}$)- SRPS ISO 8467, ISO 8467.

Thus obtained data served for determining the water pollution levels in canals based on WPI (water pollution index). This is a combined physical-chemical index which makes it possible to compare the water quality of various water bodies (independent of the presence of pollutants) (Filatov et al., 2005). Therefore, it has wide application and is used as the indicator of the quality of sea (Filatov et al., 2005) and river (Lyulko et al., 2001) waters, as well as of drinking water (Nikolaidis et al., 2007). The WPI represents the sum of ratios between the observed parameters and prescribed standard values:

$$\text{WPI}=\sum_{i=1}^{n}\frac{Ci}{SFQS}\times\frac{1}{n} \qquad (1)$$

where $C_i$ is the mean annual concentration of analysed parameters obtained on the basis of data on the water quality in canals, sampled approximately once a month. The following parameters were taken into account: dissolved $O_2$, $O_2$ saturation, pH, suspended sediments, biological oxygen demand ($BOD_5$), chemical oxygen demand ($COD_{Mn}$), nitrites, ammonium, saprobic index, metals (Fe, Mn, Ni, Hg), sulphates and coliform germs. *SFQS* represents standards of the I water quality class in Serbia, while *n* indicates the number of analysed parameters during the research.

Based on the obtained WPI values, the watercourses are classified into different classes (Tab. 1). If WPI<1, the watercourse is marked as pure, if WPI>2, the watercourse is polluted, and if WPI>6, the watercourse belongs to a group of heavily impure waters (Lyulko et al., 2001).

Table 1. Water quality classification according to WPI (Lyulko et al., 2001)

| Class | Characteristics | WPI |
|---|---|---|
| I | Very pure | ≤0.3 |
| II | Pure | 0.3-1.0 |
| III | Moderately polluted | 1.0-2.0 |
| IV | Polluted | 2.0-4.0 |
| V | Impure | 4.0-6.0 |
| VI | Heavily impure | >6 |

The cartographic method and Adobe Photoshop programme were applied for defining the spatial relations, while calculations and graphic representations are done in Microsoft Excel programme.

[1] SRPS represents officially approved label for the laboratory methods in the Republic of Serbia, and SRPS ISO is label for translated ISO methods. Certain H.Z1. symbol refers to concrete elements analysis. APHA AWWA WEF is label of the international standard methods for testing drinking and waste water. EPA 245.1 is an international method for the mercury determination in all water types, and EPA 360.2 is an international method for the determination of biological oxygen demand (BOD).

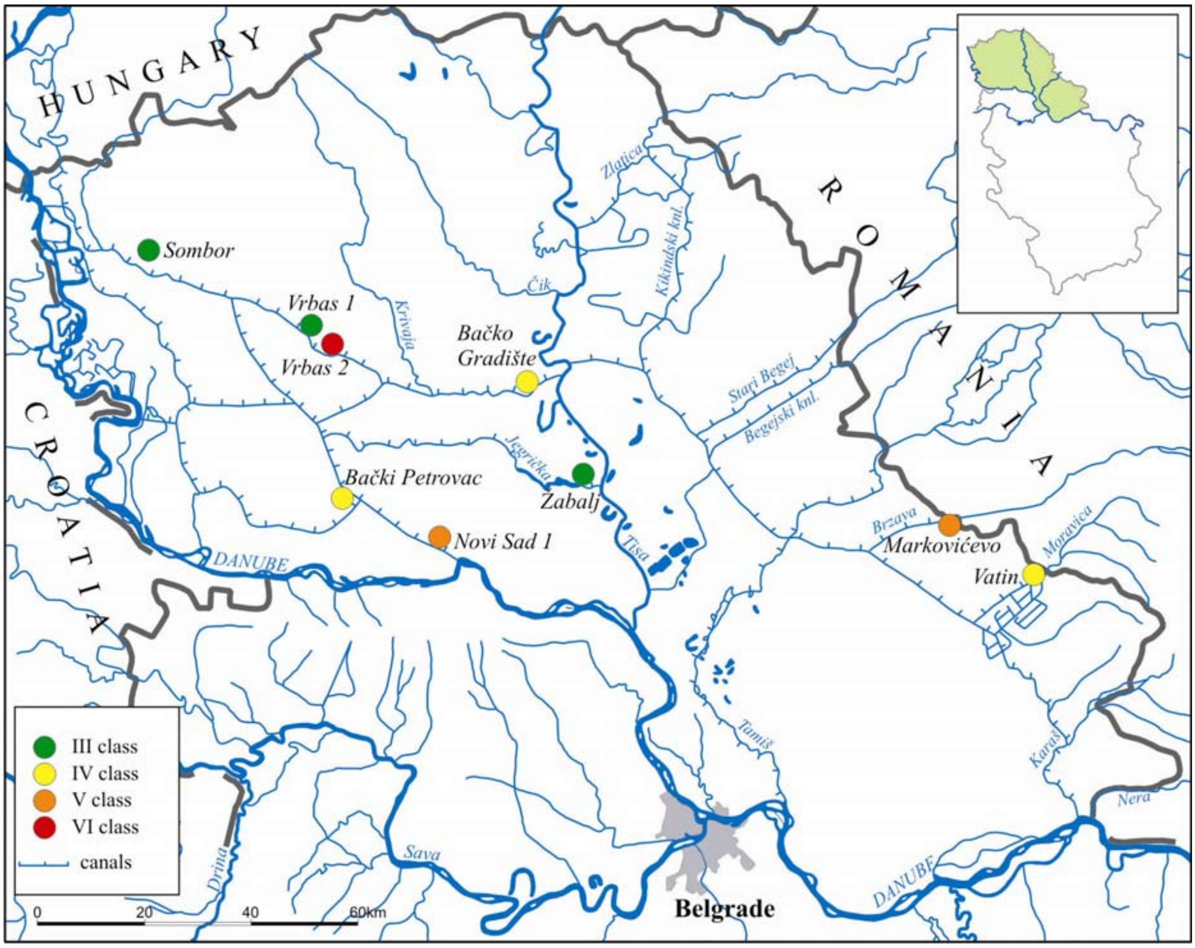


Figure 1. Location of the Hydro-system study area and hydrological sample stations with defined water quality classes based on mean WPI values for period 2004-2009

Table 2. Mean annual WPI values at hydrological stations

| Hydrological Station | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | Mean value |
|---|---|---|---|---|---|---|---|
| Sombor | 1.08 | 0.93 | 1.46 | 0.85 | 0.97 | 1.57 | 1.16 |
| Vrbas | 1.50 | 1.58 | 1.38 | 3.42 | 0.80 | 0.77 | 1.58 |
| Vrbas II | 15.97 | 18.68 | 15.95 | 17.00 | 14.87 | 16.48 | 15.32 |
| Bačko Gradište | 3.36 | 7.09 | 3.38 | 2.39 | 1.56 | 1.49 | 3.22 |
| Novi Sad I | 5.98 | 5.33 | 6.61 | 3.51 | 8.60 | 2.98 | 5.50 |
| Bački Petrovac | 2.22 | 1.38 | 2.13 | 5.10 | 1.04 | 0.74 | 2.10 |
| Žabalj I | 1.90 | 1.15 | 4.05 | 1.10 | 1.07 | 1.61 | 1.84 |
| Markovićevo | 4.49 | 5.51 | 2.24 | 4.36 | 5.84 | 1.56 | 4.04 |
| Vatin | 4.98 | 5.32 | 5.76 | 1.09 | 1.06 | 2.62 | 3.47 |

## 4. RESULTS AND DISCUSSION

Based on the data from the Tab. 2, the mean WPI values in six-year period (2004-2009) indicate that the canal water is for greater part moderately polluted or polluted at the majority of analysed profiles, i.e. the III and IV water class. Vrbas II profile has the highest mean WPI value (15.32) which classifies the water on this canal stretch as classless watercourse. The lowest mean WPI value for the analysed period is recorded at profiles Sombor (1.16) and Vrbas I (1.58), which confirms the fact that the water is moderately polluted in the area where the canal network begins.

Observing hydrological stations, the lowest WPI value was always registered at profiles Sombor and Vrbas I (they belong to the II or the III class according to the WPI values). At profile Vrbas II in

Veliki Bački canal, the annual WPI values of over 15 were registered throughout the whole period under observation which is far beyond the threshold value 6. Such values indicate an extremely high pollution, so that Veliki Bački canal is often called “waste water collector”. At the station near Bačko Gradište, the index values pointed to pollution decrease as of 2007 (VI and the IV class in the period 2004-2007, and class III from 2008). Intensive urbanisation and industrial development of Novi Sad have reflected unfavourably on the water quality of the Danube and canals in the Hydro-system Danube-Tisa-Danube. The WPI values indicate high pollution levels of canal waters (from class IV to VI). At the stations of Bački Petrovac and Žabalj, the WPI values in the six-year observation period register lower pollution compared to the above mentioned stations. At the station Markovićevo, the WPI values have changed from year to year (Tab. 2), whereas reduced canal water pollution has been registered at the station Vatin since 2007.

It is also important to analyse the annual WPI values since considerable value deviations have been noticed for the same hydrological stations in different years. Most stations have the mean annual WPI values above 1, which indicates different pollution levels of canal water. Analysed according to years, it can be stated that in 2004 the WPI values indicate class III to VI of canal water pollution. Similar state was recorded in 2005 and 2006. Throughout 2007, the quality of water in some canals of the Hydro-system Danube-Tisa-Danube improved considerably (Sombor, Bačko Gradište, Novi Sad, Žabalj and Vatin), whereas the pollution indices remained high in others. Similar canal pollution categories were registered in 2008 (except for Novi Sad and Bački Petrovac), and a similar situation was registered in 2009.

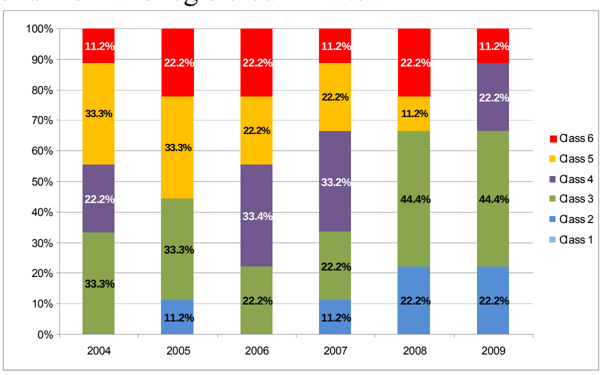


Figure 2. Classification of canal water according to WPI by year

Based on figure 2, a decreasing trend of the pollution could be generally observed as of 2007. The number of stations belonging to II (pure) and III (moderately polluted) classes increased markedly in 2008 and 2009. Also, lately, a smaller number of water samples from canals was registered as the V and the VI pollution classes.

Since we are dealing with canals that are slow running watercourses, the analyses of water levels have shown that it doesn’t affect changes in water quality and pollution (mean monthly and annual values changed negligibly). Therefore, this improvement in the canal water quality was the result of ecological projects for the rehabilitation and revitalisation of the Veliki Bački canal.

In October 2007, with a view to resolving this complex problem, the Ministry of Science and Environmental Protection, in cooperation with local self-government, Public Water Management Enterprise “Vode Vojvodine” and Institute for the Development of Water Resources “Jaroslav Černi” launched a project “The Final Resolution of the Veliki Bački canal Pollution” in the total value of 45 million Euros. At that time, the Action Plan for cleaning the Veliki Bački canal, the most polluted watercourse in Europe, was also presented. As pointed out by experts, the thickness of silt ranged from 1.5 to 2.5 m depending on sections. Since 2007, the Public Water Management Enterprise “Vode Vojvodine” carried out canal water cleansing works by sections. This programme has been partly funded by a donation of the Czech Republic. With the extraction of silt, navigation through the canal will once again be possible. The integral part of this Action Plan is also the project of the revitalisation of Veliki Bački canal on which the Institute for Water Research of Norway in cooperation with the Vojvodina Secretariat for Environmental Protection and Sustainable Development, were also engaged. The Norwegian Institute pointed to the need to construct a central waste water treatment plant. The plant has already been designed and prepared for tender procedure thanks to donations from Norway. It will be based on biological treatment so as to remove organic substances, to be later on fitted for the nitrogen removal.

Observing parameters used for the WPI calculation, a general conclusion is that their values are influenced by elements which are the indicators of organic pollution ($BOD_5$, ammonium, coliform germs, etc.), whereas the measured values of heavy metals were mainly within allowed limits or slightly above so that their effect on the canal water pollution is relatively small (Tab. 3). Metals such as nickel are important nutrients for plants, and are also used as insecticides or fungicides. However, these metals have limited mobility in soil, and anthropogenic impacts to groundwater are small (Jalgaonkar, 2008).

Table 3. Ratio of mean concentration (in the period 2004-2009) and standards of the I water quality class for analyzed parameters

| Hydr. Stat. | $O_2$ | $O_2$ sat. | pH | Susp. sed. | $BOD_5$ | Nitrites | Ammon. | Sapr. ind. | Fe | Mn | Ni | $COD_{Mn}$ | Colif. germ. | Hg | Sulphates |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sombor | 1.14 | 0.98 | 0.94 | 1.83 | 1.42 | 0.40 | 1.25 | 2.31 | 0.27 | 0.40 | 0.34 | 0.75 | 4.67 | 0.50 | 0.18 |
| Vrbas | 1.34 | 1.18 | 0.96 | 1.40 | 1.74 | 0.33 | 1.50 | 1.41 | 0.33 | 0.40 | 0.27 | 0.85 | 11.32 | 0.36 | 0.24 |
| Vrbas II | 0.33 | 0.25 | 0.86 | 4.49 | 54.60 | 1.67 | 71.6 | 1.69 | 0.73 | 1.76 | 0.41 | 4.81 | 86.10 | 0.20 | 0.29 |
| Bačko Gradište | 1.20 | 1.10 | 0.97 | 3.40 | 8.07 | 1.23 | 9.60 | 1.45 | 0.33 | 0.6 | 1.34 | 1.32 | 17.13 | 0.32 | 0.22 |
| Novi Sad I | 1.13 | 0.97 | 0.94 | 1.50 | 2.20 | 0.93 | 2.40 | 1.40 | 0.40 | 0.40 | 0.45 | 0.72 | 68.64 | 0.32 | 0.16 |
| Bački Petrovac | 1.11 | 1.00 | 0.93 | 1.64 | 2.46 | 0.87 | 2.21 | 1.40 | 0.49 | 2.60 | 0.14 | 0.73 | 15.45 | 0.22 | 0.15 |
| Žabalj I | 1.13 | 0.96 | 0.97 | 3.29 | 2.40 | 0.37 | 3.42 | 1.43 | 0.63 | 0.52 | 0.21 | 1.22 | 10.63 | 0.22 | 0.19 |
| Markov. | 1.21 | 1.01 | 0.91 | 6.61 | 1.32 | 1.13 | 2.60 | 1.43 | 0.63 | 1.00 | 0.28 | 0.65 | 41.69 | 0.10 | 0.14 |
| Vatin | 1.11 | 0.92 | 0.93 | 4.93 | 1.36 | 0.47 | 2.20 | 1.46 | 0.87 | 4.60 | 0.18 | 1.10 | 31.40 | 0.33 | 0.20 |

It would be important to present parameters which influence the pollution most. Among the most significant ones is ammonium, the values of which are often above the threshold values. That points to high pollution of canals by food industry and agricultural production (cattle farms, use of pesticides, etc.). It appears that the water pollution index (WPI) is higher in areas where agriculture is practiced more intensively (Nikolaidis et al., 2008).

The increased number of coliform germs and $BOD_5$ values points to significant pollution which originates from household sewage waters and represent one of the main indicators of the waste waters pollution. Such a state can be observed based on data from Tab. 3 and Fig. 4.

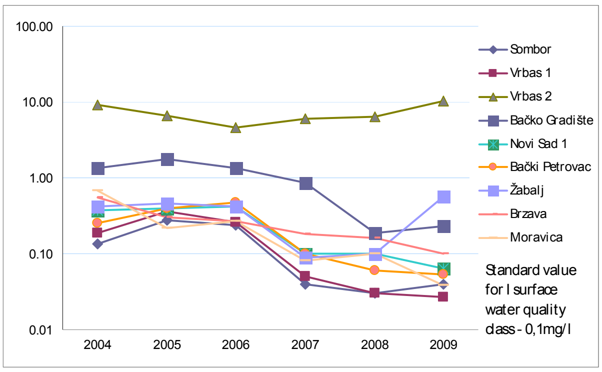


Figure 3. Mean annual ammonium values

Water pollution in Serbia is a result of human activity, and demographic characteristics on the one side, and urbanization and industrialization, on the other (Dragićević et al., 2010). Discharging of untreated waste waters from industry and households, pollution from agriculture and across-the-border inflow are the main causes of surface and ground water pollution in the Hydro-system Danube-Tisa-Danube.

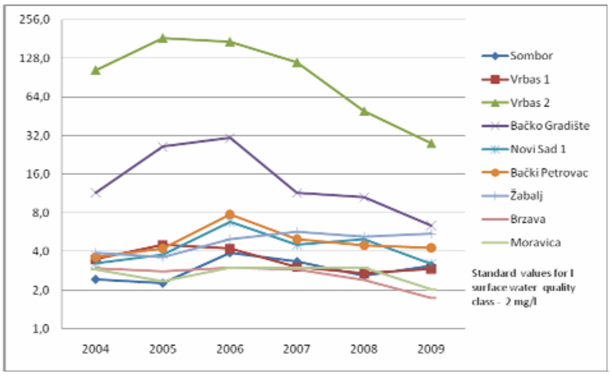


Figure 4. Mean annual $BOD_5$ values

Industry – In Serbia, approximately 95% of all industrial waste waters are discharged without previous treatment in the rivers and lakes, i.e. the main recipients (Lješević, 2002). In the Hydro-system Danube-Tisa-Danube zone, according to the quantity and concentration of harmful substances, the largest polluters are: refinery (Novi Sad), chemical industry and metallurgy plants ("Agrohem" - Novi Sad), food industries (in Novi Sad - meat industry "Neoplanta", in Vrbas - oil industry "Vital", meat industry "Carnex", sugar mill "Bačka", in Crvenka - sugar mill, in Bačka Topola - agro-industrial combine and other).

Agriculture – The influence of the agricultural production on the quality of water flows is manifold and manifested by chemical and organic pollution of soil and ground waters as a result of uncontrolled usage of various pesticides, but also through the influence of cattle breeding, i.e. cattle farms. From among larger farms in the Danube-Tisa-Danube canals zone the following stand out: Vrbas (35 000 head of cattle), Panonija (20 000 cattle), Srbobran (17 000 cattle) (Miljanović et al., 2004).

Settlements – Main pollution sources in settlements are faecal pollution resulted from the human activities, uncontrolled storage of household wastes and wastewaters discharge (either directly or insufficiently treated) (Gurzau et al., 2010). Depending on the achieved level of the utility supply in settlements (heating system, (un)constructed water supply and sewerage networks, traffic, green areas landscaping, waste disposal), different degrees of canal pollution in the Hydro-system Danube-Tisa-Danube will be registered. Only 30 % of the population of settlements in the Hidro-system catchment area is connected to the public sewerage system, while others solves the problem of waste waters over the septic tanks or in some other inadequate way (Cadastre of waste water in the territory of Vojvodina, 1995).

The most polluted canal in the Hydro-system Danube-Tisa-Danube is the frequently mentioned Veliki Bački canal, which runs from Bezdan to Bečej, and, therefore, it is an object of interest for numerous international organizations. An economic basin is located on the banks of the Veliki Bački canal with settlements Crvenka, Kula and Vrbas. Intensive economic development in the second half of the 20$^{th}$ century caused increased waste water production by industry and the population. Interesting is the fact that small town Vrbas alone discharges more waste waters than the entire city of Novi Sad and somewhat less than Belgrade. In Vrbas municipality, there are six point source polluters: meat factory, pig farm, sugar factory, edible oil factory, confectionary company and bakery. As significant contributors to overall nutrient loading and organic pollution are identified meat factory and pig farm (Grabić et al., 2011). The Veliki Bački canal cannot neutralize such high pollution, which apart from the mentioned many other smaller industrial and utility polluters contribute to, on account of its limited discharge capacity of maximum 25 $m^3/s$. The basic aim of the revitalisation, envisaged by the Action Plan, implies canal cleaning from silt and other deposits, removal of aquatic vegetation, as well as stopping all polluters from discharging unpurified waste waters into the canal. It has been scientifically demonstrated that nitrogen and phosphorous from the Veliki Bački canal reach the Black Sea, which indicates that even the broader Danube Drainage Basin is also polluted (Ilić, 2004).

## 5. CONCLUSION

Since the most developed part of Serbia is located along the banks of the Danube, both from the economic and population aspect, the largest polluters are on the banks of this river. The lack of adequate devices for the waste water treatment in factories and unplanned urbanization process which did not solve the problem of waste water evacuation represent the main causes of river and canal pollution. This problem is especially pronounced in Vojvodina because of a large number of transit rivers, the lower parts of which flow through Serbia. The Danube, the Tisa and the Tamiš enter our territory already polluted, making treatment and watercourses management work even harder. Canals of the Hydro-system Danube-Tisa-Danube ranks among the most polluted water resources in Serbia.

The WPI values in six-year period (2004-2009) go to show that the canal water is mostly moderately polluted or polluted, i.e. III or IV pollution class, respectively. The profile Vrbas II has the highest mean WPI value (15.32), which classifies the canal water at this section as classless watercourses. The lowest mean WPI value for analysed period was registered at profiles Sombor (1.16) and Vrbas I (1.58), where the canal network starts. In the period 2004-2006, the WPI values indicated the III to the VI canal water pollution class, whereas as of 2007 the pollution decreased in some canals of the Hydro-system Danube-Tisa-Danube. General conclusion is that the values of the parameters indicators of organic pollution ($BOD_5$, ammonium, coliform germs, etc.) are far above limits, indicating the predominance of organic pollution in this area. This is a consequence of the activities of food industry, agricultural production and household sewage waters. The highest pollution was registered in the Veliki Bački canal with 400 000 $m^3$ of silt deposited.

Even though there are adequate laws and regulations, little has been done on the protection of waters in Serbia. Major contributors to such situation are certainly the disregard of rivers and lenient sanctions for failure to observe regulations. In May 2010 the new Law on Waters was adopted, which should help resolve numerous problems regarding water resources pollution.

In view of great problems with the Hydro-system Danube-Tisa-Danube, the World Bank approved a 120 million Euros worth loan to Serbia for the rehabilitation of this system. The loan will be used for canal cleaning, which will improve the quality of field irrigation in Vojvodina. In addition, lately large donations have been made and projects launched by many European countries for the revitalisation of this canal network.

The solution for the protection of the water quality and environment in general, lies in the construction of adequate waste water treatment plants. One of the proposals for the central waste water treatment plant in the Hydro-system Danube-Tisa-Danube zone was given by the Institute for Water Research of Norway. The plant will be based on biological treatment aiming at removing organic substances, while later on it will be fitted for nitrogen removal. Also, the concept of "water catchment downstream from the user's waste water discharge" should be useful for the preservation of good water quality in canals.

The EU Strategy for the Danube Region, that should be adopted in the first half of 2011, is of special significance for the further study and protection of the Danube region. Fourteen countries have participated in designing this important European strategy, including Serbia, while one of its basic objectives is also environmental protection and prevention of natural crises. Good-quality projects will be financed from different funds, and one of the projects for Serbia would be cleaning and revitalisation of canals in the Danube-Tisa-Danube Hydro-system.

**Acknowledgements**

This paper is a part of scientific project 47007 supported by Ministry of Science and Technological Development of the Republic of Serbia

**REFERENCES**

**Bjeljac, Ž., Radovanović, M. & Milanović, A.,** 2004. *The River Water Resources of the Plains of Serbia: Theirs Utilization for Agriculture and the Generation of Hidro-Electricity and Some Ecological Implications.* The rational Use and Conservation of Water resources in a Changing Environment, International Conference, IGU Commision for Water Suistanabillity, Yerevan State University, NGO International Scientific research Center on Water, Climatic and Recreational Resources, Yermenia, 134-138.

**Bordalo, A.A., Teixeira, R. & Wiebe, W.J.,** 2006. *A Water Quality Index Applied to an International Shared River Basin: The Case of the Douro River.* Environmental Management, 38, 910-920.

**Burnod-Requia, K.,** 2004. *Rapid Environmental Assessment of the Tisza River Basin.* UNEP/ROE, UNEP/DEWA/GRID~Europe, in collaboration with UNEP/Vienna-ISCC, 65 p.

**Cude, C.G.,** 2001. Oregon *Water Quality Index A Tool For Evaluating Water Quality Management Effectiveness.* Journal of the American Water Resources Association, 37, 1, 125-137.

**Dragicević, S., Nenadović, S., Jovanović, B., Milanović, M., Novković, I., Pavić, D. & Lješević, M.,** 2010. *Degradation of Topciderska river water quality (Belgrade).* Carpathian Journal of Earth and Environmental Sciences, 5, 2, 177-184.

**Erba, S., Buffagni, A., Holmes, N., O'Hare, M., Scarlett, P. & Stenico, A.,** 2006. *Preliminary testing of River Habitat Survey features for the aims of the WFD hydro-morphological assessment: an overview from the STAR Project.* Hydrobiologia, 566, 281-296.

**Filatov, N., Pozdnyakov, D., Johannessen, O., Pettersson, L. & Bobylev, L.,** 2005. *White Sea: Its Marine Environment and Ecosystem Dynamics Influnced by Global Change.* Springer & Praxis Publishing, UK, 472 p.

**Gavrilović, Lj. & Dukić, D.,** 2002. *Rivers of Serbia.* Serbian State Company of Textbooks , Belgrade , 218 p.

**Grabić, J., Bezdan, A., Benka, P. & Salvai, A.,** 2011. *Spreading and Transformation of Nutrients in the Reach of the Becej-Bogojevo canal, Serbia.* Carpathian Journal of Earth and Environmental Sciences, 6, 1, 277-284.

**Guan, H., Wang, W., Jiang, Q., Hong, H. & Zhang, L.,** 2005. *A Statistical Model for Evaluating Water Pollution in Jiulong River Watershed.* Environmental Informatics Archives, 3, 185–192.

**Gurzau, A.E., Popovici, E., Pintea, A., Popa, O., Pop, C. & Dumitrascu, I.,** 2010. *Quality of Surface Water Sources from a Central Transylvanian Area as a Possible Problem for Human Security and Public Health.* Carpathian Journal of Earth and Environmental Sciences, 5, 2, 119-126.

**Güler, C., Thyne, G.D., McCray, J.E. & Turner, A.K.,** 2002. *Evaluation of graphical and multivariate statistical methods for classification of water chemistry data.* Hydrogeology Journal, 10, 455–474.

**Ilić, M.,** 2004. *Review of the Environment State and Problems in Serbia and Their Causes.* Environment Capacity Building Program, 2003, An EU Funded Project Manage by the European Agency for Reconstruction, 24 p.

**Jalgonkar, A.,** 2008. *Microanalysis of groundwater elements with respect to time and depth in the Hortobágy region in Hungary.* Carpathian Journal of Earth and Environmental Sciences, 3, 1, 39-47.

**Kamp, U., Binder, W. & Hölzl, K.,** 2007. *River habitat monitoring and assessment in Germany*. Environmental Monitoring and Assessment, 127, 1-3, 209-226.

**Lyulko, I., Ambalova, T. & Vasiljeva, T.,** 2001. *To Integrated Water Quality Assessment In Latvia.* MTM (Monitoring Tailor-Made) III, Proceedings of International Workshop on Information for Sustainable Water Management, Netherlands, 449-452.

**Lješević, M.,** 2002. *Environmental Science - Rural Ecology.,* Faculty of Geography, University of Belgrade, 182 p.

**Milanović, A., Urošev, M. & Milijašević, D.,** 2006. *Use of the RHS Method in Golijska Moravica River Basin.* Bulletin of the Serbian Geographical Society, 86, 2, 53-61.

**Miljanović, D., Kovačević-Majkić, J. & Milanović, A.,** 2004. *Environmental analysis in the zone of Corridor X in Serbia*. Bulletin of the Serbian Geographical Society, 84, 2, 165-181.

**Nikolaidis, C., Mandalos P. & Vantarakis A.,** 2008. *Impact of intensive agricultural practices on drinking water quality in the EVROS Region (NE GREECE) by GIS analysis.* Environmental Monitoring and Assessment, 143, 1-3, 43-50.

**Ocokoljić, M., Milijašević, D. & Milanović, A.,** 2009. *Rivers classification of Serbia according to the theirs pollutions degree.* Collection of the papers, Faculty of Geography, University of Belgrade, 57, 7-19.

**Raven, P.J., Holmes, N.T.H., Naura, M. & Dawson, F.H.,** 2000. *Using river habitat survey for environmental assessment and catchment planning in the U.K.* Hydrobiologia, 422-423, 359-367.

**Raven, P.J., Holmes, N.T.H., Charrier, P., Dawson, F.H., Naura, M. & Boon, P.J.,** 2002. *Towards a harmonized approach for hydromorphological assessment of rivers in Europe: a qualitative comparison of three survey methods.* Aquatic Conservation: Marine and Freshwater Ecosystems, 12, 405-424.

**Raven, P., Holmes, N., Dawson, H. & Withrington, D.**, 2005. *River Habitat Survey in Slovenia-Results from 2005.* Environment Agency, UK., (CEH Project Number: C02813), 25 p.

**Samsonova, P. & Šarapatka B.,** 2005. *Minimizing Danube River Pollution through Organic Farming:The Situation in the Czech Republic, the Slovak Republic, Hungary, Serbia and Montenegro and Bulgaria.* A Study for the REC Hungary international project: The Support and Promotion of Ecological Agriculture in the Production Areas Located in the Danube Basin. Bioinstitut, o.p.s. Olomouc, 90 p.

**Sa´nchez, E., Colmenarejo, M.F., Vicente, J., Rubio, A., Garcı´a, M.G., Travieso, L. & Borja, R.,** 2007. *Use of the water quality index and dissolved oxygen deficit as simple indicators of watersheds pollution.* Ecological Indicators, 7, 315–328.

**Shepherd. K. & Csagoly P.,** 2007. *Tisza River Basin Analysis 2007, Summary Report - A call for action.* ICPDR – International Commission for the Protection of the Danube River, Vienna, Austria, 20 p.

**Shrestha, S. & Kazama, F., 2007**. *Assessment of surface water quality using multivariate statistical techniques: A case study of the Fuji river basin, Japan.* Environmental Modelling & Software, 22, 464-475.

**Simeonova, V., Stratisb, J.A., Samarac, C., Zachariadisb, G., Voutsac, D., Anthemidis, A., Sofonioub, M. & Kouimtzisc, Th.,** 2003. *Assessment of the surface water quality in Northern Greece.* Water Research, 37, 4119–4124.

**Singha, K.P., Malika, A., Mohana, D. & Sinhab, S.,** 2004. *Multivariate statistical techniques for the evaluation of spatial and temporal variations in water quality of Gomti River (India)—a case study.* Water Research, 38, 3980–3992.

**Urošev, M., Milanović, A., Milijašević, D.,** 2009. *Assessment of the river habitat quality in undeveloped areas of Serbia applying the RHS (river habitat survey) method*. Journal of the Geographical Institute „Jovan Cvijić" SASA, 59, 2, 37-58.

**Vega, M., Pardo, R., Баrrado, E. & Debân, L.,** 1998. *Assessment of Seasonal and Polluting Effects on the Quality of River Water by Exploratory Data Analysis.* Water Resources, 32, 12, 3581-3592.

**Veljković, N. & Jovičić, M.,** 2007. *Danube river water quality analysis using Water Quality Index methodology.* Proceedings from Conference on Actual Problems of Water Use and Protection, Yugoslav Society for the Water Protection, 36, 49-54.

**Veljković, N., Lekić, D. & Jovičić, M.,** 2008. *Case study of Integrated Water Quality Management: Serbian Water Quality Index***.** Proceedings from XXIVth Conference of the Danubian Countries on the Hydrological Forecasting and Hydrological Bases of Water Management, Slovenian National Committee for the IHP UNESCO, 171-178.

**Department of Chemistry, Faculty of Sciences,** (1995). *Cadastre of waste water in the territory of Vojvodina.* Novi Sad: Department of Chemistry, Faculty of Sciences, 854 p.

**Republic Hydrometeorological Service of Serbia**. (2004–2009). *Annual Report – Water quality.* Belgrade: Republic Hydrometeorological Service of Serbia

Received at: 22. 11. 2010
Revised at: 16. 04. 2011
Accepted for publication at:04. 06. 2011
Published online: 09. 06. 2011