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Water Quality Trends of the Tisa River Along its Flow Through Serbia

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1. Introduction

The Tisa River is the longest tributary of the Danube River. It originates by joining two watercourses, the White and the Black Tisa. It is an international river which flows through Ukraine, Romania, Slovakia, Hungary and its lower part is in Serbia. A small part of its basin is located in Serbia, only about 6%. The total catchment area is 157220 km^2, of which 24% is in mountainous region, 32% in hilly and 34% is in lowland (ICPDR 2016). Since the lowland part of Hungary has been often flooded, in the nineteenth century extensive river regulation works were performed reducing its length from 1419 km to 966 km. After accomplishing the works 589 km of riverbed remained cut off from the river and 136 km of new riverbed has been excavated (Pavic et al. 2009). However, even after a large number of cuts of accented river bends, the Tisa River still represents one of the most uniform meandering watercourses in the world (Czaya 1998). Since 1972 the lower part of the Tisa River is exposed to the effects of backwater from the dam Djerdap on the Danube and from 1977 the section upstream from Novi Becej is exposed to the effects of backwater from the dam near Novi Becej, built at 65 river-km. Due to this causes flow regime of the Tisa has changed compared to earlier natural condition (Skoric 2014).

The Tisa River runs through Serbia along its downstream section 164 km in length. It confluences the Danube opposite to Stari Slankamen

(Gavrilovic & Dukic 2002). The river has a character of meandering, slow flowing watercourse which speed has additionally been slow down along a section upstream of the dam near Novi Becej. In the average the Tisa is the richest with water during the spring, with maximal flow rates and water level in April, while during autumn months in September and October flow rates and water levels are minimal (Pavic & Mesaros 2006, Pavic et al. 2009). The average flow rate of the Tisa is about 830 $m^3 s^{-1}$, which represent 5.6% of the total runoff of the Danube basin (Savic et al. 2014).

The largest number of tributaries, including the most powerful, such as the Moris and the Samos, the Tisa receives upstream, along its flow trough Hungary. In Serbia, the only larger tributary is the Begej River. Besides, it receives waters after joining with the Keres, canalized Zlatica, the Adjanska bara, the Cik, canal Hs DTD Novi Becej – Bezdan and the Jegricka. Baring in mind that the most of the Tisa's basin is located outside Serbia this river enters Serbia already polluted (Skoric 2014).

The Tisa is one of the most important watercourses in Serbia and has great significance for water management of the region, especially since it has become a central part of the Hydrosystem Danube-Tisa-Danube (Hs DTD). Together with the Danube it represents the source of water supply for the Hs DTD and is also a recipient of excess and waste water (Skoric 2014). The area of Vojvodina (the northern part of Serbia), through which the Tisa River flows, is dominated by flatland with about 85% of agricultural land and 75% of arable land. However, it was concluded that concentrated pollutants originating from settlements and industries still have more significant impact on the quality of surface waters in comparison to agriculture (Becelic-Tomin et al. 2015, Besermenji et al. 2011, Savic et al. 2017, Vujovic et al. 2013). Used water degrade ecosystem of the canal system, especially during the summer months. Water quality is of crucial importance for the public water supply, agriculture, industry, the development of forestry, fishing, nautical tourism and recreation (Andjelkovic et al. 2014, Cramer & Kistinger 2003, Csatho et al. 2007, Rodic et al. 2003).

It should be noted that the natural boundaries of the Tisa River basin, within this area have been disturbed after construction of the Hs DTD. The system of sluices and other hydrotechnical facilities has established an artificial water regime and enabling water redirection within the canal network between the Tisa and the Danube River.

The paper presents comparative analysis of indicators of the quality of the water body Tisa along its flow through Serbia and their trends. The examination of trends was confined to the trends over time, the period from 2004 to 2014. The quantification of trends was performed and their significance was demonstrated.

2. Materials and Methods

The scope of this analyses are water quality data of the Tisa River for period 2004-2014, obtained from monitoring points located along its flow through Serbia: Martonos, Novi Becej and Titel. Data sources for water quality parameters, used in this paper, were the Republic Hydrometeorological Service of Serbia and the Agency for Environmental Protection of the Republic of Serbia. Water quality parameters, chosen for this analysis, were those physical-chemical parameters used for assessment of water bodies, i.e. for classification and are sampled monthly in average:

- Conductivity (EC) $\mu S\ cm^{-1}$,
- Dissolved oxygen (DO) $mg\ dm^{-3}$,
- Biochemical oxygen demand (BOD_5) $mg\ dm^{-3}$,
- Chemical oxygen demand (COD) $mg\ dm^{-3}$,
- Nitrates (NO_3) $mg\ dm^{-3}$ and
- Total phosphorus (Tot. P) $mg\ dm^{-3}$.

This water quality analyses encompassed 2376 data in total.

On the basis of a set of measurements of parameters, from the measuring points, samples were formed. Numerical characteristics of the samples were obtained using the average annual values, which were further exploited for analysis and interpretation of results. Applied methods:

- Basic statistical data processing

Mean annual values were obtained by calculating the arithmetic mean of the measured parameter values during the year.

- Linear regression for determining trend

Linear regression for obtaining regression lines is a common procedure for calculation based on a data set containing pairs of observations (X_i, Y_i) in order to obtain an inclination that best fits the data. In the case of temporal data, value X_i represents the time, while Y_i represents a value of parameters of the studied phenomena. Assessment of the trend is obtained from the slope of the regression line, as a measure of the severity of the trend. Trends of the analyzed parameters were obtained from the sign of the coefficients of direction of regression lines, determined by linear regression. Statistical analysis of linear regression, of mean annual values of the parameters analyzed, has been performed by the application of statistical functions executed in Microsoft Office Excel 2007.

- Mann-Kendall non-parametric test for assessing the significance of the trend together with Sen's method for assessing slope (US EPA 2006, Veljkovic & Jovicic 2009, Zelenakova et al. 2015).

Mann-Kendall test enables quantifying the trend, slope evaluation and proof that the trend assessment is statistically different from zero. Sen's method, used for the evaluation of slope, was applied for calculating slope of all pairs of temporal points. Furthermore, the average of all slopes is used as the score of the total slope. If there are n temporal points and Yi denotes the data value for the i-th temporal point, if there are no missing data, then there will be $n(n-1)/2$ possible pairs of temporal points (i, j), where $i < j$. The slope of this pair of points represents the change in the value of the time interval and is expressed by the formula:

$$Q = (Yj - Yi)/(j - i) \tag{1}$$

where:
Q – the slope between the data Yi and Yj,
Yi – temporal data i,
Yj – temporal data j,
j – any time after time i.

Moreover, statistic S (Mann-Kendall S) is calculated, which represents the difference between the number of positive and negative values of Q by the formula:

$$S = \sum Q(+) - \sum Q(-) \tag{2}$$

If there is no trend, then the number of positive and negative slopes will be about the same, and S will be close to zero. In the case where the number of positive slopes prevails ($S \gg 0$), an ascending trend can be expected and vice versa, if the negative slopes are prevalent ($S \ll 0$), a descending trend can be expected. After determining the slope of all Q, obtained Q values are ranked in ascending sequence. Finally, the median of the Q' is determined, which represents the score of the slope.

Sen's estimate determines median Q’ of the series according to formula (3) or (4) which represents score of the slope:

$$Q' = Q[(N' + 1)/2] \quad \text{if N' is odd} \quad (3)$$

$$Q' = (Q[(N'/2] + Q[(N' + 2)/2] \quad \text{if N' is even} \quad (4)$$

where:
N’ – number of calculated slopes.

This method is used for determining if obtained median is statistically different from zero. Interval of trust of the median is determined by estimating the level of upper and lower bounds of the trust interval using slopes of appropriate rank. For two-sided confidence interval around the median of the slope, at the first place z is determined for certain confidence, i.e. two-sided 95% $z_{(1-0,05/2)} = z_{0.975} = 1.96$. Furthermore, estimate of the variance is calculated using Mann-Kendall statistics S, developed by Kendall, 1975 (US EPA 2006, Veljkovic & Jovicic 2009, Zelenakova et al. 2015), according to the formula:

$$\mathrm{VAR(S)} = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{q} tp(tp-1)(2tp+5)\right] \quad (5)$$

where:
n – number of data of the examined sample,
q – number of different Q data which are repeating,
tp – number of repeating of each of the Q data which is repeating.

Then statistics z_0 is calculated by formula:

$$z_0 = \frac{S - \mathrm{sign}(S)}{\sqrt{\mathrm{VAR(S)}}} \quad (6)$$

where:
S – Mann-Kendall statistics S,

$$\mathrm{sign(S)}\begin{cases} 1 \text{ if } S > 0 \\ 0 \text{ if } S = 0 \\ -1 \text{ if } S < 0 \end{cases}$$

To determine the extent of rank for required confidence interval, C_α value is determined by the formula:

$$C_\alpha = z_{(1-\alpha/2)} \sqrt{\mathrm{VAR(S)}} \quad (7)$$

where:
$z_{(1-\alpha/2)}$ – critical values for the selected threshold of significance after the Normal distribution.

Using values C_α the rank of the lower (M_1) and upper (M_2+1) bounds of the confidence interval are determined by the formula (8) and (9):

$$M_1 = (N' - C_\alpha)/2 \quad (8)$$

$$M_2 = (N' + C_\alpha)/2 \quad (9)$$

Values (M_1) and (M_2+1) are representing serial numbers of the slope Q in the regulated growing sequence. If zero (change of sign) does not lie between the upper and lower bounds of the confidence interval, then it can be concluded that the median of the slope is statistically significant for the required level of significance.

- Assessment of the Tisa River water quality

The assessment of water quality has been carried out on the basis of multi-year average annual values of parameters obtained by calculating the arithmetic mean of average annual value, in a similar manner as in a study of (Kanownik & Policht-Latawiec 2015, Sojka & Murat-Blazejewska 2009, Veljkovic & Jovicic 2009, Zelenakova et al. 2015).

Table 1. National water quality classification of surface waters bodies, Velike nizijske reke (Official Gazette RS 74/2011, 50/2012)
Tabela 1. Krajowa klasyfikacja jakości wód powierzchniowych, Velike nizijske reke (Official Gazette RS 74/2011, 50/2012)

Parameters	Limit values for classes				
	I	II	III	IV	V
EC (μS cm^{-1})	<1000	<1000	1000-1500	1500-3000	>3000
DO (mg dm^{-3})	>8.5	8.5-7	7-5	5-4	<4
BOD_5 (mg dm^{-3})	<2	2-5	5-8	8-20	>20
COD (mg dm^{-3})	<5	5-10	10-20	20-50	>50
NO_3 (mg dm^{-3})	<1	1-3	3-6	6-15	>15
Tot. P (mg dm^{-3})	<0.05	0.05-0.2	0.2-0.4	0.4-1	>1

Comprehensive revision of water policy is present in the EU member countries, where among others the rules of Water Framework Directive (WFD) were introduced and implemented (Mrozik et al. 2015). In Serbia current classification and criteria for water quality were used for the assessment in the paper (Table 1), (Official Gazette RS 74/2011, 50/2012), all harmonized with the Water Framework Directive (Directive 2000/60/EC).

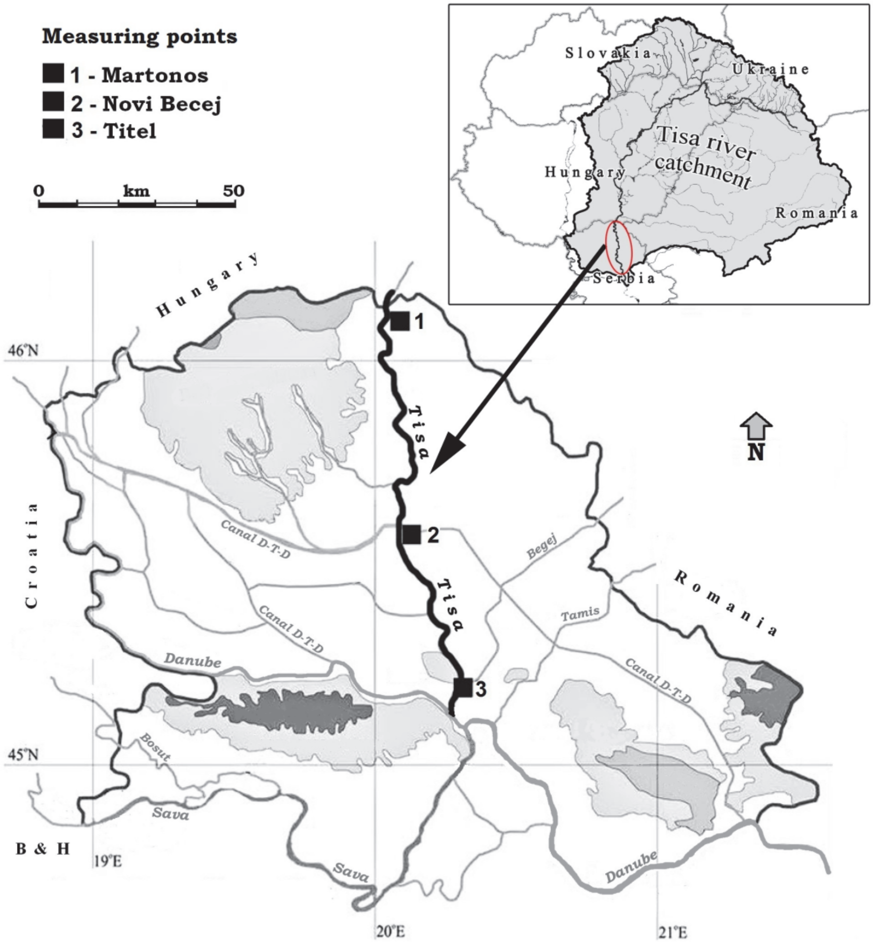

Fig. 1. Location of the measuring points on the Tisa River in Serbia
Rys. 1. Lokalizacja punktów pomiarowych na rzece Tisa w Serbii

Figure 1 shows position of the measuring points along the Tisa River in Serbia, which water quality monitoring data were used in this analyses, while Table 2 presents detailed description of the measuring points, as well as the hydrological characteristics (Distance: the distance in km from the mouth of the Tisa River; Catchment: the area in square km, from which water drains towards the measuring point; Sampling location in profile: L – Left bank, M – Middle of the river, R – Right bank).

Table 2. List of measuring points on the Tisa River in Serbia
Tabela 2. Lista punktów pomiarowych na rzece Tisa w Serbii

Location name/ Measuring point	Latitude d. m. s.	Longitude d. m. s.	Distance (river-km)	Catchment (km^2)	Profile location
Martonos	46 06 52	20 05 13	155.0	135130	R
Novi Becej	45 35 06	20 08 30	65.0	145415	L
Titel	45 11 52	20 19 07	8.7	157174	M

3. Results and Discussion

Table 3 and Figures 2, 3 and 4 are showing the average annual and multiannual values of the analyzed water quality parameters of the Tisa River (EC, DO, BOD_5, COD, NO_3 and Tot. P), for the period 2004-2014. Water quality at all measuring points (Martonos, Novi Becej and Titel) is assessed according to the contemporary regulations (Official Gazette RS 74/2011, 50/2012), prescribed criteria and reference values. All average annual values belong to I and II classes. Therefore, it can be concluded that, the ecological status of the Tisa River is excellent to good that is also in line with the requirements of the WFD (Directive 2000/60/EC).

However, when index of degradation quality (IDQ) was applied (Savic et al 2014), which is defined by the quotient value of the parameters on the downstream and upstream measuring point, quality degradation processes are present in the section Matonos – Novi Becej (parameters: dissolved oxygen IDQ=0.88, BOD_5 IDQ=1.16 and COD IDQ=1.04). The reason is most probably due to backwater from the dam near Novi Becej. On the downstream section Novi Becej – Titel quality degradation processes are not significantly expressed. Lescesen et al. (2014) draw similar conclusions reached by the application of water quality index (WQI) on the Tisa for the period 2003-2012 at measuring points: Martonos, Novi Becej and Titel.

Table 3. Water quality assessment of the Tisa River in Serbia, average values and classes of ecological status for the period 2004-2014
Tabela 3. Ocena jakości wody rzeki Tisa w Serbii, wartości średnie i klasy stanu ekologicznego w latach 2004-2014

Measuring points	EC ($\mu S\ cm^{-1}$)	DO ($mg\ dm^{-3}$)	BOD_5 ($mg\ dm^{-3}$)	COD ($mg\ dm^{-3}$)	NO_3 ($mg\ dm^{-3}$)	Tot. P ($mg\ dm^{-3}$)
Martonos	excellent class I 438.44	excellent class I 10.09	excellent class I 1.89	good class II 5.09	good class II 1.06	good class II 0.148
Novi Becej	excellent class I 439.19	excellent class I 8.86	good class II 2.19	good class II 5.27	good class II 1.05	good class II 0.147
Titel	excellent class I 438.81	excellent class I 8.91	good class II 2.01	good class II 5.16	good class II 1.02	good class II 0.145

According to the results of water quality analysis overall conclusion is that the Tisa and the catchment area that belongs to Serbia is under pressure from pollution directly from polluters situated along its course, as well as from canals of the Hs DTD. Due to the small decline, which in the lower reaches of the Tisa is only 4.5 cm km^{-1}, self-purification is slower. The biggest share of pollution originates from the canal network. On some sections of the Hs DTD in Backa degradation of water quality is constantly present (Grabic et al. 2016, Milanovic et al. 2011, Pantelic et al. 2012).

Degradation of canal water quality is accelerated after joining of the Krivaja River, which is one of the most polluted rivers in Serbia (Savic et al. 2014). Furthermore, the greatest danger threatening the Tisa is from hasardous pollution. Last such accident happened in the spring of 2000, when from the Samos River, Romanian tributary of the Tisa, large amounts of cyanide and heavy metals reached the Tisa. Contamination has been so great that the use of water and fish from the Tisa and the Danube in Serbia was prohibited during four months (Pavic et al. 2010).

Changes in the quality of the water bodies of the Tisa River at measuring points in the period 2004-2014 are presented with regression lines, trends lines for analyzed parameters, at Figures 2-4. In the Figures 2, 3 and 4 and in Table 4, in the equations of regression lines, the value x represents the ordinal number of years for which the parameter values are given (x = 1, 2, ..., 11).

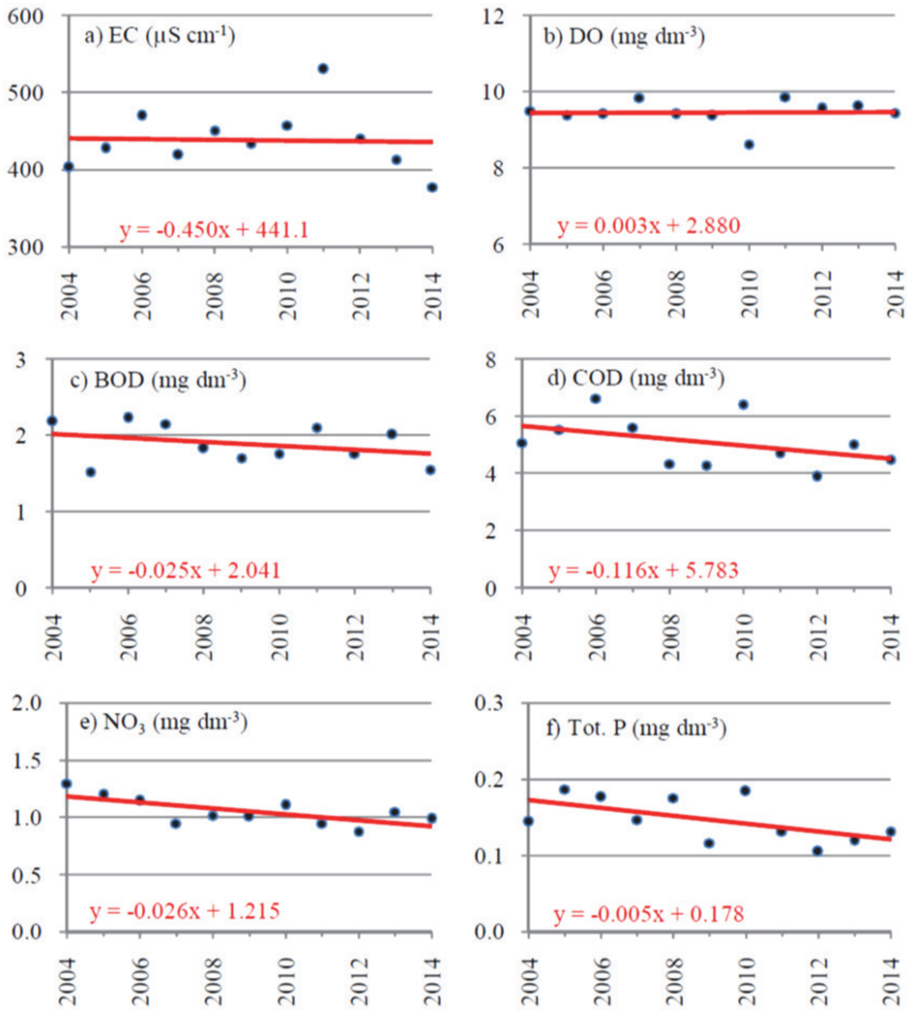

Fig. 2. The Tisa River, measuring point Martonos, average annual values of water quality parameters and regression lines; (x – ordinal number of years, x = 1, 2, ..., 11)

Rys. 2. Rzeka Tisa, punkt pomiarowy Martonos, średnie roczne wartości parametrów jakości wody i linie regresji; (x – liczba porządkowa lat, x = 1, 2, ..., 11)

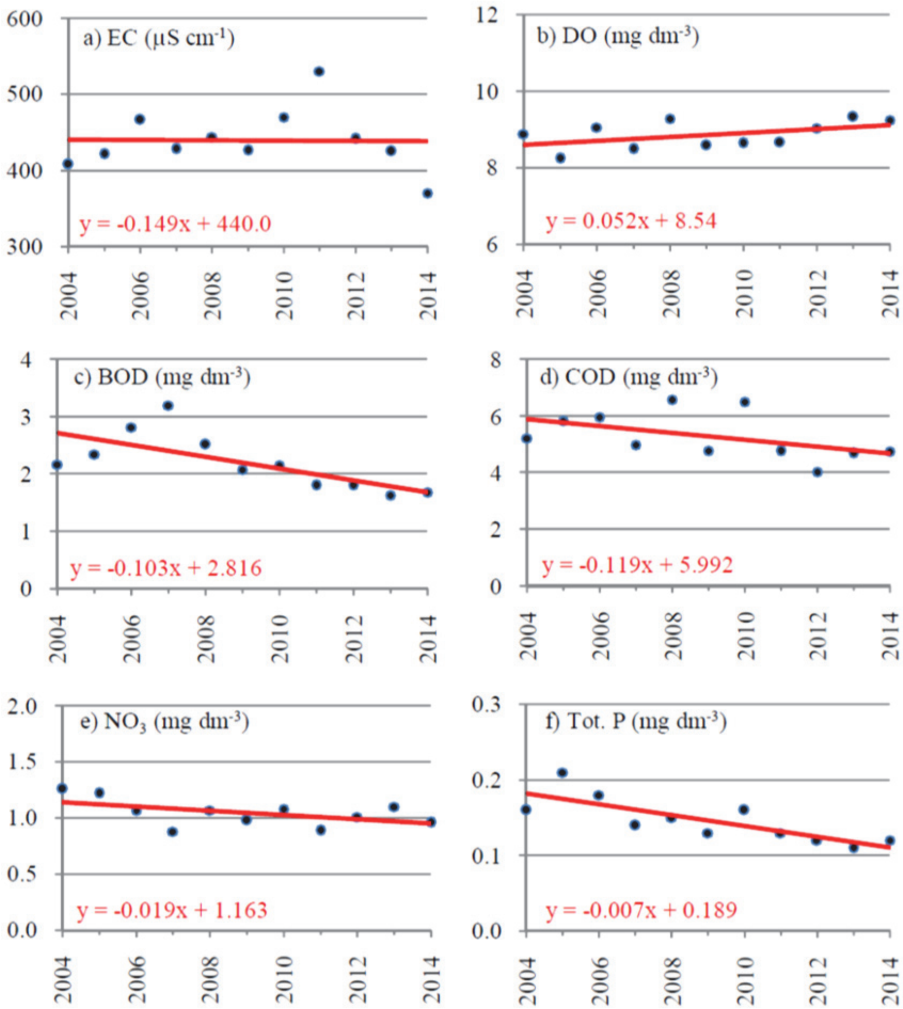

Fig. 3. The Tisa River, measuring point Novi Becej, average annual values of water quality parameters and regression lines (x – ordinal number of years, x = 1, 2, ..., 11).

Rys. 3. Rzeka Tisa, punkt pomiarowy Novi Becej, średnie roczne wartości parametrów jakości wody i linie regresji; (x – liczba porządkowa lat, x = 1, 2, ..., 11)

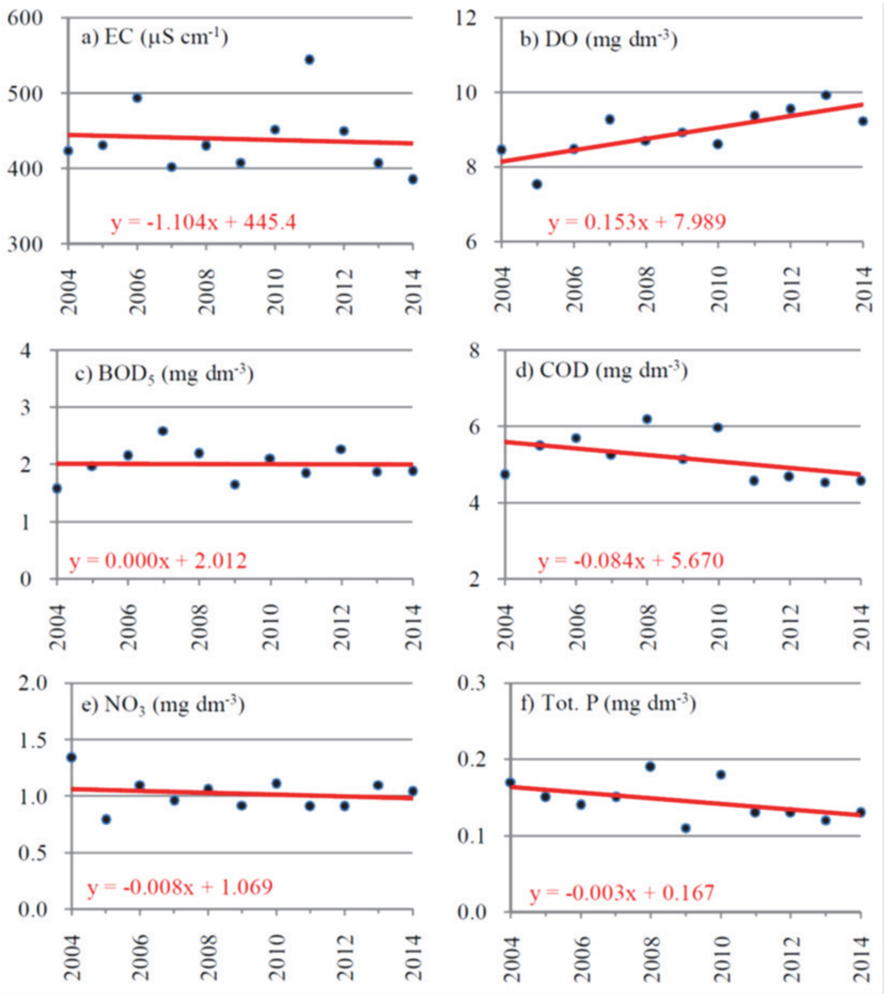

Fig. 4. The Tisa River, measuring point Titel, average annual values of water quality parameters and regression lines (x – ordinal number of years, x = 1, 2, ..., 11)

Rys. 4. Rzeka Tisa, punkt pomiarowy Titel, średnie roczne wartości parametrów jakości wody i linie regresji; (x – liczba porządkowa lat, x = 1, 2, ..., 11)

Applied Mann-Kendall test enabled the quantification of the trend, rating of slope and proving that the assessment of the trend is statistically different from zero at a significance level of α=0.05. The results of the analysis of the significance of the trend are shown in Table 4. For the parameters analyzed from the measuring point: Martonos, Novi Becej and Titel, regression lines are given, as well as statistics S which sign represents the direction of the trend, calculated estimates of variance Var(S) of the statistics S, statistics z_0 and the probability p determined by finding the probability p $(Z > |z_0|)$ to test the existence of a trend.

Table 4. Trend analysis of water quality parameters at the measuring points using the Mann-Kendall test
Tabela 4. Analiza trendów parametrów jakości wody w punktach pomiarowych przy użyciu testu Mann-Kendall

Param.	Linear regression	Mann-Kendall statistic (S)	Var(S)	Z_0	p	Increasing/ Decreasing trend (↗/↘)
			Martonos			
EC	y = -0.450x + 441.1	-1	165.00	0.00	0.5000	no trend
DO	y = 0.003x + 2.880	6	165.00	0.39	0.3485	no trend
BOD_5	y = -0.025x + 2.041	-16	151.33	-1.22	0.1112	no trend
COD	y = -0.116x + 5.783	-17	163.00	-1.25	0.1056	no trend
NO_3	y = -0.026x + 1.215	-28	132.00	-2.35	0.0094	**Decreasing↘**
Tot. P	y = -0.005x + 0.178	-22	155.00	-1.69	0.0455	no trend
			Novi Becej			
EC	y = -0.149x + 440.0	3	165.00	0.16	0.4364	no trend
DO	y = 0.052x + 8.540	23	157.00	1.76	0.0392	no trend
BOD_5	y = -0.103x + 2.816	-34	146.00	-2.73	0.0032	**Decreasing↘**
COD	y = -0.119x + 5.992	-25	159.00	-1.90	0.0287	no trend
NO_3	y = -0.019x + 1.163	-16	134.67	-1.29	0.0985	no trend
Tot. P	y = -0.007x + 0.189	-39	152.33	-3.08	0.0010	**Decreasing↘**
			Titel			
EC	y = -1.104x + 445.4	-7	165.00	-0.47	0.3192	no trend
DO	y = 0.153x + 7.989	35	162.00	2.67	0.0038	**Increasing↗**
BOD_5	y = 0.000x + 2.012	3	150.67	0.16	0.4364	no trend
COD	y = -0.084x + 5.670	-22	159.00	-1.67	0.0475	no trend
NO_3	y = -0.008x + 1.069	-7	139.33	-0.51	0.3050	no trend
Tot. P	y = -0.003x + 0.167	-21	152.33	-1.62	0.0526	no trend

According to the normal distribution, at the threshold of significance α=0.05, for two-sided test, the critical value of $z_{(1-\alpha/2)}$ for the normal distribution is $z_{(1-0,05/2)} = z_{0.975} = 1.96$. The results showed existence of trends along the analyzed section: decreasing at measuring points Martonos and Novi Becej, and increasing at measuring point Titel. For most of the parameters, although the trend line shows the growth or decline (e.g. in Figures 2f, 3b and 4d), applied methodology has not confirmed their significance.

In Table 5 median estimates of trends by Sen's method are given. At the level of significance of α=0.05, for the two-sided confidence interval of 95%, values (M_1) and (M_2+1) determine the rank of the lower and upper bounds of the confidence interval and are representing number of the growing series of slopes, while (Q_{M1}) and (Q_{M2+1}) of the slope value.

Table 5. Estimate of the median slope of water quality parameters using Sen's method
Tabela 5. Szacowanie średniego nachylenia parametrów jakości wody przy użyciu metody Sen

Parameter	Median of slope Q′	M_1	M_2+1	Q_{M1}	Q_{M2+1}	Significance of the slope
Martonos						
EC	-6.05	14.91	41.10	-36.7300	30.6100	no significance
DO	0.03	14.91	41.10	-0.1840	0.2100	no significance
BOD_5	-0.13	15.45	40.56	-0.3900	0.1260	no significance
COD	-0.53	14.99	41.02	-1.2403	0.3810	no significance
NO_3	-0.10	16.23	39.77	-0.2000	-0.0223	**Significant**
Tot. P	-0.03	15.30	40.70	-0.0506	0.0027	no significance
Novi Becej						
EC	4.13	14.91	41.10	-38.5429	33.8770	no significance
DO	0.23	15.22	40.78	-0.0356	0.5202	no significance
BOD_5	-0.39	15.66	40.34	-0.7100	-0.1530	**Significant**
COD	-0.45	15.14	40.86	-1.1886	0.0588	no significance
NO_3	-0.09	16.13	39.78	-0.1800	0.0178	no significance
Tot. P	-0.03	15.41	40.61	-0.0448	-0.0102	**Significant**
Titel						
EC	-15.65	14.91	41.10	-43.2463	2.7570	no significance
DO	0.63	15.03	40.98	0.1815	0.9990	**Significant**
BOD_5	0.03	15.48	40.53	-0.3100	0.2512	no significance
COD	-0.34	15.14	40.86	-0.9200	0.0988	no significance
NO_3	-0.01	15.94	40.07	-0.1518	0.1207	no significance
Tot. P	-0.02	15.41	40.61	-0.0366	0.0052	no significance

Based on presented results, in most (14) cases there is no significant trend, but it is confirmed that there are also significant trends: for nitrates at the measureing point Martonos; BOD_5 and total phosphorus at the measuring point Novi Becej and for dissolved oxygen at the measuring point Titel. The signs of these significant trends speak in favor of future improvements in the quality of a the water body Tisa in Serbia.

4. Conclusion

The Tisa River is one of the most important watercourses in Serbia. The river has significant water importance for water management, especially since it has become a central hydrological junction of the Hs DTD. Together with the Danube it represents the source of the water supply for the Hs DTD and at the same time it receives excess and waste water. According to the results of the analysis of water quality overall conclusion is that the water body Tisa, within basin belonging to Serbia, is under pressure from pollution originating, either directly from polluterse located along its course and from tributaries – rivers and the canal Hs DTD. Assessment of quality of the water body was carried out using the current classification criteria of the Republic of Serbia, harmonized with WFD. Reference conditions for achieving excellent ecological status, i.e. class I, are achieved for conductivity and dissolved oxygen observed along the flow (measuring points: Martonos, Novi Becej and Titel) and BOD_5 at measuring point Martonos. Downstream at measuring points Novi Becej and Titel, for BOD_5, water quality belongs to class II. According to the concentration of the parameters COD, nitrates and total phosphorus water quality belongs exclusively to class II.

Trend analysis of water quality using the Mann-Kendall test in most (14/18) cases, i.e. in 78%, confirmed the non-existence of a significant trend. Therefore, it can be concluded that water quality during the past decade is stable. A statisticaly significant trend was confirmed in 4 cases: nitrates (measuring point Martonos, descending trend), BOD_5 and total phosphorus (measuring point Novi Becej, descending trend), and dissolved oxygen (measuring point Titel, increasing trend).

The signs of these statsiticaly significant trends are speaking in favor of future improvements in the quality of the water body Tisa in Serbia. Esentially, all values of these parameters are belonging to excellent or good ecological status, i.e. I or II water quality class, which attainment is required by the Water Framework Directive.

References

Andjelkovic, A., Djekovic, V., Milosevic, N. (2014). Quality control of the water and sludge in Palic lake. [In Serbian]. *Forestry, 1-2*, 113-129.

Becelic-Tomin, M., Dalmacija, B., Stanojevic, D., Pesic, V., Krcmar, D., Kerkez, D., Tomasevic, D. (2015). Current and planned activities in the field of water management in Serbia. *International Journal of Sanitary Engineering Research, 9(1)*, 14-20.

Besermenji, S., Kosi, K., Vujacic, M. (2011). Pollution of water resources in vojvodina. *Geographica Timisiensis, 20(2)*, 5-12.

Cramer, T. & Kistinger, S. (2003). Risk and water resource management in the Tisa River basin. *Wasser und Boden, 55(5)*, 33-37.

Csatho, P., Sisak, I., Radimszky, L., Lushaj, S., Spiegel, H., Nikolova, M.T., Nikolov, N., Cermak, P., Klir, J., Astover, A., Karklins, A., Lazauskas, S., Kopinski, J., Hera, C., Dumitru, E., Manojlovic, M., Bogdanovic, D., Torma, S., Leskosek, M., Khristenko A. (2007). Agriculture as a source of phosphorus causing eutrophication in Central and Eastern Europe. *Soil Use and Management, 23(1)*, 36-56.

Czaya, E. (1998). *The rivers of the Earth*. Budapest: Gondolat.

Directive 2000/60/EC of the European Parliament and the Council of 23 October 2000 establishing a framework for Community action in the field of water policy (L 327/1 of 22.12.2000).

Gavrilovic, LJ. & Dukic, D. (2002). *Rivers of Serbia*. [In Serbian]. Belgrade: Zavod za udzbenike i nastavna sredstva.

Grabic, J., Bezdan, A., Benka, P., Josimov Dundjerski, J., Salvai, A. (2016). Water quality management for preserving fish populations within Hydrosystem Danube-Tisa-Danube, Serbia. *Carpathian Journal of Earth and Environmental Sciences, 11,* 235-243.

ICPDR – International Commission for the Protection of the Danube River, Tisza Basin, Last visited: 6th of December, 2016. (https://www.icpdr.org/main/danube-basin/tisza-basin)

Kanownik, W. & Policht-Latawiec, A. (2015). Changeability of oxygen and biogenic indices in waters flowing through the areas under various anthropopressure. *Polish Journal of Environmental Studies, 24(4)*, 1633-1640.

Lescesen, I., Pantelic, M., Dolinaj, D., Lukic, T. (2014). Assessment of water quality of the Tisa river (Vojvodina, North Serbia) for ten year period using Serbian Water Quality Index (SWQI). *Geographica Pannonica, 18,* 102-107.

Milanovic, A., Milijasevic, D., Brankov, J. (2011). Assessment of polluting effects and surface water quality using water pollution index: a case study of Hydro-system Danube-Tisa-Danube, Serbia. *Carpathian Journal of Earth and Environmental Sciences. 6*, 269-277.

Mrozik, K., Przybyla, Cz, Pyszny, K. (2015). Problems of the Integrated Urban Water Management. The Case of the Poznan Metropolitan Area (Poland). *Rocznik Ochrona Środowiska, 17,* 230-245.

Pantelic, M., Dolinaj, D., Savic, S., Stojanovic, V., Nadj, I. (2012). Statistical analysis of water quality parameters of Veliki Bački Canal (Vojvodina, Serbia) in the period 2000-2009. *Carpathian Journal of Earth and Environmental Sciences. 7*, 255-264.

Pavic, D., Dolinaj, D., Dragicevic, S. (2009). Thermal regime of water and ice on the Tisza river in Serbia. [In Serbian]. *Collection of papers – Faculty of Geography at the University of Belgrade, 57*, 35-46.

Pavic D., Mesaros M. (2006). Navigability features of the Tisa River in Serbia as the main precondition for nautical tourism development. [In Serbian]. *Turizam, 10,* 112-115.

Pavic, D., Mesaros, M., Zivkovic, N. (2010). Water pollution and water quality of the Tisa River in Serbia. [In Serbian]. *Collection of papers – Faculty of Geography at the University of Belgrade, 58*, 47-62.

Regulation on the parameters of the ecological and chemical status of surface waters and the parameters of the chemical and quantitative status of groundwater. Official Gazette of the RS, No 74/2011.

Regulation on threshold values of limit values for pollutants in surface waters and ground waters and sediments and the deadlines for their achievement. Official Gazette of RS, No 50/2012.

Rodic, M.N., Vidovic, M.M., Vidovic, M.U. (2003). *Anthropological influences of the Tisa river.* The Sixth International Symposium and Exhibition on Environmental Contamination in Central and Eastern Europe and the Commonwealth of Independent States. Prague, 1-5.

Savic, R., Bezdan, A., Josimov Dundjerski, J., Letic, LJ., Nikolic, V., Ondrasek D. (2014). Water quality degradation of Krivaja watercourse. [In Serbian]. *Agro-knowledge Journal, 52*, 159-172.

Savic, R., Ondrasek, G., Letic, LJ., Nikolic, V., Tanaskovik, V. (2017). Nutrients accumulation in drainage channel sediments. *International Journal of Sediment Research*, *32(2)*, 180-185.

Savic, R., Pejic, B., Ondrasek, G., Vranesevic, M., Bezdan, A. (2013). Utilisation of natural resources for irrigation in Vojvodina. [In Serbian]. *Agro-knowledge Journal, 14*, 133-142.

Skoric, M. (2014). *The impact of emissions of pollution on the Tisa river and measures for improvement of the ecological and chemical status.* [In Serbian]. Master thesis. Faculty of Agriculture, University of Novi Sad.

Sojka, M., Murat-Blazejewska, S. (2009). Physico-chemical and Hydromorphological State of a Small Lowland River. [in Polish]. *Rocznik Ochrona Srodowiska, 11*, 727-737.

United States Environmental Protection Agency (US EPA) (2006). *Data Quality Assessment: Statistical Methods for Practitioners EPA QA/G-9S*. Washington, USA: Office of Environmental Information.

Veljkovic, N., Jovicic, M. (2009). Nitrate concentrations Trends in Serbian watercourses. [In Serbian]. *Voda i sanitarna tehnika (Water and Sanitary Engineering), 39(1)*, 23-30.

Vujovic, S., Kolakovic, S., Becelic-Tomin, M. (2013). Evaluation of significantly modified water bodies in Vojvodina by using multivariate statistical techniques. *Hemijska industrija, 67(5)*, 823-833.

Zelenakova, M., Purcz, P., Oravcova, A. (2015). Trends in water quality in Laborec River, Slovakia. *Procedia Engineering, 119*, 1161-1170.

Trendy zmian jakości wody rzeki Tisa wzdłuż jej biegu przez Serbię

Abstract

The problem of the paper is water quality of the water body Tisa which geographically belongs to Serbia. The scope of the analyses are water quality monitoring data of the Tisa River at tree measuring points along its flow through Serbia: Martonos, Novi Becej and Titel in period 2004-2014. The analyses encompassed conductivity, dissolved oxygen, BOD_5, COD, nitrates and total phosphorus. Assessment of water quality has been conducted by the application of contemporary classifications and criteria of the Republic of Serbia. Reference conditions for achieving excellent ecological status, I class of water quality are achieved for conductivity, dissolved oxygen, along investigated section (measuring points: Martonos, Novi Becej and Titel) and BOD_5 at the measuring point Martonos. Downstream at measuring points Novi Becej and Titel for BOD_5 water quality belongs to class II. According to concentrations of COD, nitrates and total phosphorus water quality belongs exclusively to class II. Linear regression analyses was applied for determining trend lines of parameters, while Mann-Kendell test in most cases (14/18), i.e. 78%, has confirmed nonexistence of significant trend. Water quality during the past decade is stable. A statistically significant trend was confirmed in 4 cases: nitrates (measuring point Martonos, descending trend), BOD_5 and total phosphorus (measuring

point Novi Becej, descending trend), and dissolved oxygen (measuring point Titel, increasing trend). Signs of these trends speak in favor of future improvement of water quality of the Tisa River in Serbia.

Streszczenie

W artykule opisano jakość wody w rzece Tisa, która geograficznie należy do Serbii. Zakres analiz obejmuje są dane dotyczące jakości wody w rzece Tisa w punktach pomiarowych wzdłuż biegu przez Serbię: Martonos, Novi Becej i Titel w latach 2004-2014. Analizą objęto: przewodnictwo, tlen rozpuszczony, BZT_5, ChZT, azotany i fosfor ogólny. Ocena jakości wody została przeprowadzona przez zastosowanie aktualnej klasyfikacji i kryteriów w Republice Serbii. Warunki parametrów odpowiadające doskonałemu stanowi ekologicznemu, I klasy jakości wody, osiągnięto dla przewodności, tlenu rozpuszczonego, wzdłuż całego badanego odcinka (punkty pomiarowe: Martonos, Novi Becej i Titel) oraz BZT_5, w punkcie pomiarowym Martonos. W dolnym biegu rzeki, w punktach pomiarowych Novi Becej i Titel dla BZT_5 wody należą do klasy II. Jeśli chodzi o ChZT, azotany i fosfor całkowity jakość wody należy do klasy II. W celu określenia linii trendu parametrów zastosowano analizę regresji liniowej, a test Manna-Kendalla, w większości przypadków (14/18), tj. 78%, potwierdził brak znaczącego trendu. Jakość wody w ciągu ostatnich dziesięciu lat jest stabilna. W 4 przypadkach stwierdzono statystycznie istotną tendencję: azotany (punkt pomiarowy Martonos, tendencja spadkowa), BZT_5 i fosfor ogólny (punkt pomiarowy Novi Becej, tendencja spadkowa) oraz tlen rozpuszczony (punkt pomiarowy Titel, tendencja wzrostowa). Trendy mogą oznaczać poprawą jakości wody rzeki Tisa w Serbii w przyszłości.

Słowa kluczowe:
jakość wody, zanieczyszczenie, trend, test Manna-Kendalla, samooczyszczanie

Keywords:
water quality, pollution, trend, Mann-Kendall test, self-purification