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Original Scientific Paper

IDENTIFICATION OF LOCATIONS WITH POTENTIAL SOURCES OF POLLUTION IN THE TISA RIVER BASIN

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Abstract. *The paper analyzes the values of selected parameters of SM, OS, pH, NH4-N, POP4-P, and BOD-5 at measuring points of Martonoš, Novi Bečej, Titel, Hetin, Bačko Gradište and Bački Breg in order to identify locations with potential sources of pollution in the Tisa River basin in Serbia. The interdependence between the locations and the observed most influential parameters of water pollution indicators was analyzed using one-way analysis of variance (ANOVA), followed by a posthoc Tukey-Kramer test to learn more about statistically significant different values of parameters at the observed locations. The results of the applied statistical analysis and post-hoc test show a significant difference in values of parameters NH4-N, BOD-5 and PO4-P at the location of Bačko Gradište, identifying it as a location with potential sources of pollution, where additional measures must be taken to protect and prevent pollution of watercourses in this part of the Tisa River Basin as an integral part of the environment*.

Key words: *Tisa River basin, sources of pollution, ANOVA.*

1. INTRODUCTION

The Tisa River originates in Ukraine, in the Carpathians, in the area of Bukovina, and its basin includes Ukraine, Romania, Slovakia, Hungary and, finally, Serbia, where near Stari Slankamen, this river flows into the Danube. The Tisa River is 964km long in total (whereas 164km in Serbia), while its catchment area is 157,186 km^2. Part of the Tisa basin in Serbia receives water from the Begej River (flowing from Romania to Serbia) and other tributaries indirectly through the Danube-Tisa-Danube canal system. The Tisa

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River in Vojvodina has tributaries from both Banat and Bačka sides. Despite the small part of the Tisa basin that belongs to Serbia, this area has a significant impact on the groundwater regime, which is the main source of water supply. Accordingly, the monitoring and the assessment of water quality in the Tisa River basin is of great importance, and it is the subject of numerous studies [1,2,3].

Different multivariate statistical techniques and methods to assess water quality are often used in research. Among the most commonly used methods for monitoring periodic and spatial changes in water quality are one-way analysis of variance (ANOVA), Pearson correlation, Factor analysis (FA), and principal components analysis (PCA) [4,5]. Also, various studies use these statistical methods to point out the main sources of pollution in water [6,7,8].

Some of the results obtained using PCA and FA techniques have shown that variations in water quality in the Tisa River basin occur mainly under the influence of dissolved salts (from natural sources) and organic substances and nutrients from various anthropogenic sources (agricultural production, food industry, wastewater discharges, etc.) [9].

The aim of this paper is to find out more about the significantly different values of parameters between the observed locations using one-way analysis of variance (ANOVA), followed by a posthoc Tukey-Kramer test, and thus to identify locations with potential sources of pollution in the Tisa River basin in Serbia. According to previously conducted investigations [9], organic pollutants and nutrients that mostly affect the water quality in the basin were analyzed.

2. Methodology

The one-way analysis of variance (ANOVA) is a significant statistical approach used to determine whether there are any statistically significant differences between the means of the independent groups. The null hypothesis of the ANOVA predicts that the group means are equal, while the alternative expects that there is at least two group means that are statistically significantly different from each other. One-way ANOVA is a useful and extensive test of statistics. However, it does not provide additional information on patterns or comparisons between specific groups. In order to reveal which groups significantly differ from each other, the Tukey post-hoc test is done.

The Tukey Test, also known as Tukey's Honest Significant Difference test, is a post-hoc test based on the studentized range distribution and it is used to point out where the differences between significant results lay [10]. Thus, while the ANOVA test shows if the results are significant overall, post-hoc test provides information on exactly where those differences occur within the group.

The test statistic used in Tukey's test is denoted q and is essentially a modified t-statistic that corrects for multiple comparisons. q can be found similarly to the t-statistic:

$$q_{\alpha,k,N} - k \tag{1}$$

The studentized range distribution of q is defined as:

$$q_s = (Y_{\max} - Y_{\min})/SE \tag{2}$$

Where Y_{max} and Y_{min} are the larger and smaller means of the two groups being compared, while SE is defined as the standard error of the entire design.

The statistical analysis is done by JMP Statistical Discovery v10.0 software. The aim of the statistics is to find out if there is a statistically significant difference within each of the 6 parameters (SM, OS, pH, NH4-N, POP4-P, BOD-5) measured at the most significant locations in the Tisa basin (Martonoš, Novi Bečej, Titel, Hetin, Bačko Gradište and Bački Breg). This would confirm the statistical validity of the results and statistically confirm the interdependence between the locations and the observed most influential parameters. Variance homogeneity is conducted by the Bartlett test, while data normality was checked by Shapiro – Wilk normality test. After checking necessary assumptions, one-way ANOVA was performed, followed by a posthoc Tukey-Kramer test to find out more about the significantly different values of parameters between the observed locations.

3. Results and Discussion

After checking necessary assumptions (variance homogeneity conducted by Bartlett test and normality of the data checked by Shapiro – Wilk normality test), one-way ANOVA is performed (Table 1). It took 6 ANOVA analyses for each parameter through

Table 1 Significantly different values of parameters between locations

Location	Location	Difference	Std Err Dif	Lower CL	Upper CL	p-Value
			SM			
Martonoš	Hetin	92.25000	27.72367	10.8030	173.6970	0.0175*
Martonoš	Bački Breg	90.25000	27.11428	10.5933	169.9067	0.0174*
Martonoš	Bačko Gradište	87.43182	27.72367	5.9848	168.8788	0.0283*
			OS			
Bačko Gradište	Hetin	38.09091	9.541095	10.0609	66.12088	0.0023*
Bačko Gradište	Bački Breg	35.53788	9.340208	8.0981	62.97768	0.0042*
			pH			
Bački Breg	Martonoš	0.3216667	0.0628115	0.137138	0.5061953	<.0001*
Bački Breg	Titel	0.2633333	0.0628115	0.078805	0.4478620	0.0012*
Bačko Gradište	Martonoš	0.2554545	0.0642232	0.066779	0.4441304	0.0024*
Bački Breg	Novi Bečej	0.2533333	0.0628115	0.068805	0.4378620	0.0020*
Bački Breg	Hetin	0.2043939	0.0642232	0.015718	0.3930698	0.0262*
Bačko Gradište	Titel	0.1971212	0.0642232	0.008445	0.3857971	0.0355*
			NH4-N			
Bačko Gradište	Hetin	0.2536364	0.0564333	0.087846	0.4194270	0.0004*
Bačko Gradište	Martonoš	0.2341667	0.0552451	0.071867	0.3964666	0.0010*
Bačko Gradište	Bački Breg	0.2308333	0.0552451	0.068533	0.3931332	0.0012*
Bačko Gradište	Novi Bečej	0.2258333	0.0552451	0.063533	0.3881332	0.0017*
Bačko Gradište	Titel	0.2258333	0.0552451	0.063533	0.3881332	0.0017*
			POP4-P			
Bački Breg	Novi Bečej	0.7904167	0.0822884	0.548668	1.032165	<.0001*
Bački Breg	Martonoš	0.7886667	0.0822884	0.546918	1.030415	<.0001*
Bački Breg	Titel	0.7825000	0.0822884	0.540752	1.024248	<.0001*
Bački Breg	Bačko Gradište	0.7660758	0.0841379	0.518894	1.013257	<.0001*
Bački Breg	Hetin	0.5025303	0.0841379	0.255349	0.749712	<.0001*
Hetin	Novi Bečej	0.2878864	0.0841379	0.040705	0.535068	0.0133*
Hetin	Martonoš	0.2861364	0.0841379	0.038955	0.533318	0.0141*
Hetin	Titel	0.2799697	0.0841379	0.032788	0.527151	0.0175*
Hetin	Bačko	0.2635455	0.0859475	0.011048	0.516043	0.0358*
			BOD-5			
Bačko Gradište	Novi Bečej	2.661364	0.7744766	0.38609	4.936632	0.0128*
Bačko Gradište	Titel	2.569697	0.7744766	0.29443	4.844966	0.0179*
Bačko Gradište	Martonoš	2.519697	0.7744766	0.24443	4.794966	0.0215*

(Note: * stands for obtained p-value that is <0.05) each location to be performed (Fig. 1). After the ANOVA confirmed that at least one place has a statistically different value than others, a post-hoc Tukey-Kramer test is performed to find out more about the significantly different values of parameters between the locations. To emphasize statistically significant values, only p-values that are found to be less than 0.05 are taken into consideration and shown in Table 1.

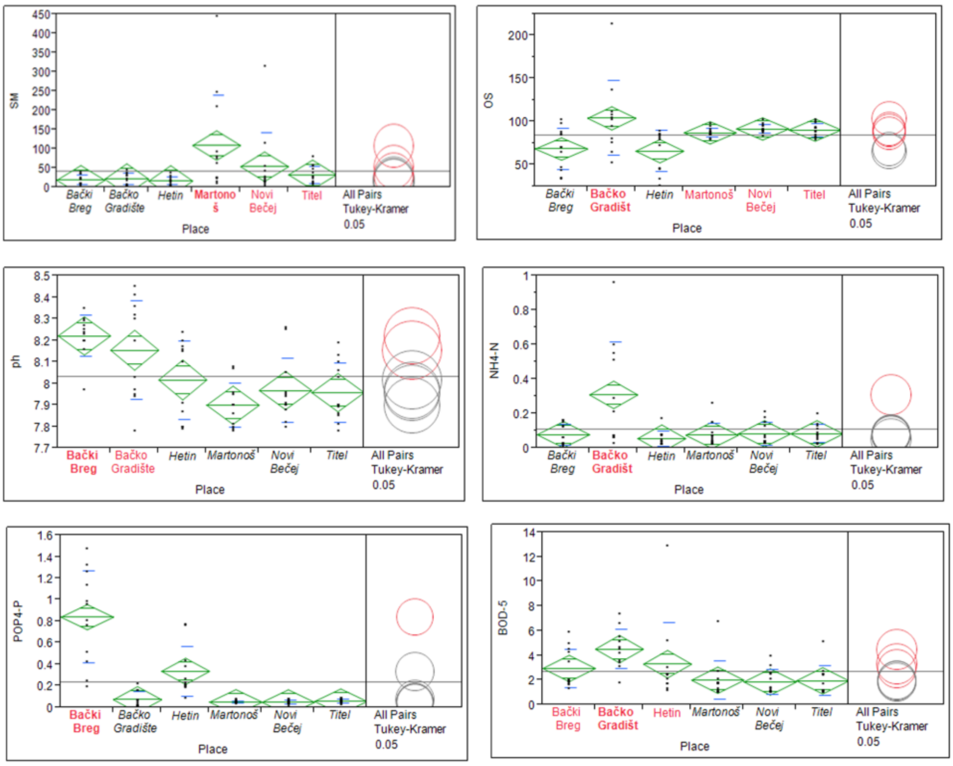

Fig. 1 The mean diamond graph presenting the input data with the results of Tukey-Kramer test

The one-way ANOVA of SM parameter by location has shown that at least one location has a statistically different value of SM than others (obtained p -value is 0.009). Since the p-value is less than 0.05 the result is considered statistically significant. Additionally, a posthoc test shows the significantly different SM values between locations: Martonoš - Hetin (p-value 0.0175), Martonoš - Bački Breg (p-value 0.0174) and Martonoš - Bačko Gradište (p-value 0.0283).

The one-way Anova of OS parameter by location has shown that at least one location has a statistically different value than others (obtained p -value is 0.0008), so the posthoc test marked off the significantly different OS values between Bačko Gradište - Hetin (p-value 0.0023) and Bačko Gradište - Bački Breg (p-value 0.0042).

In regards to pH parameter, the one way ANOVA obtained p-value is <0.001, so it again allowed the Tukey – Kramer post-hoc test to point out the significantly different pH values between locations Bački Breg - Martonoš (p-value <0.001), Bački Breg - Titel (p-value

0.0012), Bačko Gradište - Martonoš (p-value 0.0024), Bački Breg - Novi Bečej (p-value 0.002), Bački Breg - Hetin (p-value 0.0262) and Bačko Gradište - Titel (p-value 0.0355).

According to the one way ANOVA obtained p -value of NH4-N parameter by location (p-value 0.0002), indicating to at least one place with a statistically different value than others, post-hoc test showed that significantly different NH4-N values can be found between locations Bačko Gradište - Hetin (p-value 0.0004), Bačko Gradište - Martonoš (p-value 0.001), Bačko Gradište - Bački Breg (p-value 0.0012), Bačko Gradište - Novi Bečej (p-value 0.0017) and Bačko Gradište - Titel (p-value 0.0017). It means that location Bačko Gradište has significantly different NH4-N values compared to the values measured at other locations.

The one way ANOVA of POP4-P parameter by location has shown that at least one place has a statistically different value than others (obtained p -value is <0.001), so after the Tukey – Kramer post-hoc test is conducted, three different groups of locations (according to the content of POP4-P in water) are found to be significantly different: Bački Breg, Hetin and the group consisted of Bačko Gradište, Titel, Martonoš and Novi Bečej.

Due to the obtained p-value of BOD-5 parameter by location, one way ANOVA has also shown that at least one place has a statistically different value than others (obtained p -value is <0.0061), and the following Tukey–Kramer post-hoc test pointed out the significantly different BOD-5 values between places Bačko Gradište -Novi Bečej (p-value 0.0128), Bačko Gradište -Titel (p-value 0.0179) and Bačko Gradište -Martonoš (p-value 0.0215).

Monthly measured values of the parameters in the observed one-year period, at each measuring station, together with the results of the Tukey-Kramer test are shown in Fig. 1. The input data are presented using the mean diamond graph. The right part of the figure shows comparison circles with the results of Tukey-Kramer test. The circles represent locations. The differently colored circles (locations) have a statistically significant difference in the observed parameter (for each parameter separately). The names of the locations (i.e. colored circles) are also colored on the left part of the figure for better understanding and presentation of the results.

The locations with the highest values of concentrations of the observed parameters were highlighted in red. Based on the results shown, it can be concluded that the concentration of SM parameters is highest at the Martonoš location, while the Bačko Gradište location has the highest values of OS, NH4-N and BOD-5 parameters; Bački breg location has the highest measured values of pH and POP4-P. This leads to the conclusion that the location of Bačko Gradište is a location with significant sources of pollution in the Tisa River basin in relation to other observed locations.

Bačko Gradište is located on the widest part of the Veliki Bački Canal, which is part of the DTD (Danube-Tisa-Danube) system and is considered the most polluted watercourse in Europe. Part of the canal’s pollution flows into the Tisa River and contains degradable organic pollution identified by increased concentrations of BOD-5 at this location. Increased concentrations of NH4-N at the identified location of Bačko Gradište indicate pollution that originates mainly from diffuse sources of pollution of anthropogenic origin (agriculture, artificial fertilizers, and wastewater discharges).

4. Conclusion

The results of the applied statistical analysis and a post-hoc test show statistically significant differences in the values of parameters at the observed locations, indicating specific parameters that are the cause of deviations in these locations in the Tisa River basin. Locations with significant deviations in the values of parameters NH4-N, BOD-5 and PO4-P indicate pollution by nutrients as well as by those of the organic origin, which is in accordance with previously conducted research. Bačko Gradište stands out as a location with higher potential sources of pollution in the Tisa River basin compared to other observed locations, which identifies it as a location with potential sources of pollution where additional measures must be taken to protect and prevent pollution of watercourses in this part of the Tisa River basin as an integral part of the environment.

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IDENTIFIKACIJA LOKACIJA SA POTENCIJALNIM IZVORIMA ZAGAĐENJA U SLIVU REKE TISE

Rad analizira vrednosti odabranih parametara SM, OS, pH, NH4-N, POP4-P i BOD-5 na mernim mestima Martonoš, Novi Bečej, Titel, Hetin, Bačko Gradište i Bački Breg sa ciljem identifikacije lokacije sa potencijalnim izvorima zagađenja u slivu reke Tise u Srbiji. Međuzavisnost između lokacija i posmatranih najuticajnijih parametara pokazatelja zagađenja vode analizirana je korišćenjem metode analize varijanse (ANOVA) i post hoc Tukey-Kramerovog testa da bi se saznalo više o statistički značajno različitim vrednostima parametara na posmatranim lokacijama. Rezultati primenjene statističke analize i post-hoc testa pokazuju značajno odstupanje vrednosti parametara NH4-N, BOD-5 i PO4-P na lokaciji Bačko Gradište, identifikujući je kao lokaciju sa potencijalnim izvorima zagađenja gde se moraju preduzeti dodatne mere za zaštitu i sprečavanje zagađenja vodotoka u ovom delu sliva reke Tise kao sastavnog dela životne sredine.

Ključne reči: *Sliv reke Tise, izvori zagađenja, ANOVA.*