FACTA UNIVERSITATIS
Series: **Working and Living Environmental Protection** Vol. 10, N° 2, 2013, pp. 129 - 134

RANKING OF LOCATIONS WITH POTENTIAL ENVIRONMENTAL RISK ON THE DANUBE *

UDC 504.75.05:556.06+556.53(497.11)

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Abstract. *The water quality ranking in this study was conducted using the PROMETHEE/ GAIA method based on the monitoring data collected from seventeen measuring locations on the Danube in 2009. In terms of the investigation, ten water quality parameters (conductivity, pH, suspended matter, oxygen saturation, temperature, orthophosphates, total nitrogen oxides, biochemical oxygen demand (BOD-5), ammonium ion and E.coli) were used as ranking criteria. Locations were grouped into clusters according to the mutual dependence of the parameters. The results of the PROMETHEE/GAIA analysis indicate that the location with the best water quality is Dobra (L14), while the location with the worst water quality is Pančevo (L9). The direction of concluding suggests that Pančevo (L9) is the location of the potential environmental risks that require the implementation of adequate preventive measures in order to achieve and preserve better water quality in this part of the Danube.*

Key words: *the Danube, environmental risk, the PROMETHEE/GAIA method, ranking.*

1. INTRODUCTION

The Danube, as the second largest river in Europe, with its network of canals and tributaries within its catchment area is of great importance for Europe in general, and for all of the countries located in the basin. The Danube Basin covers an area of 817.000 km^2 of which approximately 82.000 km^2 (10%) belong to the territory of Serbia. The total length of the river Danube in Serbia is 588km. It is mainly used for domestic and industrial water supply, irrigation, navigation and the cooling of thermal power plants, but the Danube also acts as receiving water for both municipal and industrial waste water effluents.

Received September 29, 2013
* **Acknowledgement**. The paper is a part of the research done within projects No. III-43014 and TP33034 funded by the Serbian Ministry for Science.

Nowadays, the protection of natural resources, especially water, is a priority task for society as a whole (Gatica et al, 2012). Ecological risk is an indicator of the probability of damage to the environment caused by exposure to certain environmental hazards. Its assessment includes the identification of the actual or potential presence of certain pollutants. Regular systematic monitoring of water quality, through appropriate institutions and services in Serbia such as the Republic Hydrometeorological Service of Serbia (RHSS), offers a large amount of research data to begin with. Monitoring involves biological as well as physical-chemical measurements of the quality, so various water quality parameters can be obtained from it and used to monitor the overall progress (Takić et al, 2012; D'heygere et al, 2002; Newman et al, 1994).

Water quality depends on different physical, chemical and biological parameters. Thus, a meaningful ranking analysis of the water quality requires multivariate projection methods (Ayoko et al. 2007; Milanović et al. 2010). For the purposes of ranking the selected locations on the Danube in terms of water quality parameters a multi-criteria decision-making analysis (MCDA) was applied, and more specifically the PROMETHEE/GAIA method (Brans, 1982). This method was widely used in a number of studies concerning different environmental issues (Khalil et al. 2004; Mutikanga et al. 2011; Nikolić et al. 2010). The application of this particular method in processing the obtained results shows certain advantages compared to other MCDA methods such as an easy way of problem structuring, a huge amount of data to process, great possibilities of quantifying quality values, fine software support (Behzadian et al. 2010; Brans et al. 1994; Macharis et al. 2004; Nikolić et al. 2010).

The aim of this paper is to explore potential changes in the water quality of the Danube measured at seventeen locations along its course and to suggest actions to prevent further pollution of the Danube in Serbia.

2. Materials and Methods

Water sampling was conducted monthly in time period from January to December 2009 by the RHSS (RHSS, 2009).

The investigation includes seventeen hydrological measuring locations at distances given from the mouth of the river: L1: Bezdan (entering point) 1425.59 km, L2: Apatin – 1401 km, L3: Bogojevo – 1367.4 km, L4: Bačka Palanka – 1298.6 km, L5: Novi Sad – 1254.98 km, L6: Slankamen – 1215.5 km, L7: Čenta – 1189 km, L8: Zemun – 1174 km, L9: Pančevo – 1154.6 km, L10: Beograd-Vinča – 1145.5 km L11: Smederevo – 1116 km, L12: Banatska Palanka – 1076.6 km, L13: Veliko Gradište – 1059.2 km, L14: Dobra – 1021 km, L15: Tekija – 956.2 km, L16: Brza Palanka – 883.8 km, L17: Radujevac (exit point) 852 km. Locations were marked as L1, L2, ... to L17, respectively.

At the sampling point, the water temperature was measured and pH value determined according to the SRPS H.Z1.111 method, the biochemical oxygen demand (BOD-5) was determined by the EPA 360.2 method, the dissolved oxygen was determined according to the SRPS H.Z1.135 method, suspended matter according to the 13.060.30 SRPS H.Z1.160 method, orthophosphates according to the standard analytical method APHA AWWA WEF 4500-P, ammonium ion according to the SRPS ISO 7150-1 method, total nitrogen oxides according to the SRPS ISO 5663 method, while the estimated number of coliform bacteria (*E. coli*) per liter was determined 48 hours after incubation at 37^{o}C (RHSS, 2009).

The ranking of the locations on the Danube in terms of water quality parameters was conducted using the PROMETHEE/GAIA methodology which was performed using the software package Decision Lab 2000 developed in collaboration with the Canadian company *Visual Decision*.

3. Results and Discussion

The ranking scenario includes the average annual values of ten water quality parameters as criteria, and seventeen locations along the Danube in Serbia as alternatives (Table 1).

Table 1 Ranking scenarios of the water quality parameters

	pH	Temperature	Conductivity	O_2 Saturation	Suspended Matter	BOD-5	Total NO_2	Orthophosphate	Ammonium	E.coli
Max/min	Min	Min	Min	Max	Min	Min	Min	Min	Min	Min
Preference Function	Linear	Linear	Linear	Linear	Linear	Linear	Linear	Linear	Linear	Linear
Indifference Threshold (Q)	5 %	5 %	5 %	5 %	5 %	5 %	5 %	5 %	5 %	5 %
Preference Threshold (P)	30 %	30 %	30 %	30 %	30 %	30 %	30 %	30 %	30 %	30 %
Unit	-	°C	µS/cm	%	mg/L	mg/L	mg/L	mg/L	mg/L	per 100 mL
L1	8.3	13.2	411.8	97.7	32.4	2.2	1.891	0.044	0.08	11498
L2	8.4	15.9	401.7	100.9	27.1	2.5	1.713	0.046	0.04	10300
L3	8.3	13.2	411.0	100.3	31.9	2.3	1.789	0.038	0.09	11350
L4	8.2	14.1	401.3	92.5	24.9	2.0	1.619	0.040	0.07	13900
L5	8.3	13.7	398.5	96.0	23.3	2.5	1.574	0.047	0.06	1727
L6	8.3	13.9	393.3	97.5	25.8	2.3	1.652	0.040	0.07	1200
L7	8.3	14.1	393.5	98.6	20.5	2.2	1.666	0.041	0.07	0.0
L8	7.8	14.0	392.9	94.2	21.8	3.1	0.751	0.073	0.11	2400
L9	8.2	14.6	398.3	95.7	31.6	2.3	1.332	0.047	0.09	18525
L10	7.8	15.0	375.0	98.7	18.4	2.5	0.680	0.061	0.13	2400
L11	7.8	14.9	381.6	96.7	17.3	2.6	0.748	0.061	0.13	2400
L12	7.9	14.5	379.9	88.7	28.8	1.5	1.364	0.049	0.15	6848
L13	7.7	14.6	377.7	91.3	13.2	1.7	0.905	0.058	0.09	7360
L14	7.9	14.1	370.0	101.4	10.8	1.7	0.864	0.054	0.08	7050
L15	7.8	15.5	369.6	93.6	8.8	1.8	0.791	0.044	0.07	12425
L16	7.8	14.5	370.6	94.8	9.3	1.5	0.934	0.056	0.10	6230
L17	7.7	15.5	372.6	93.2	9.8	1.9	0.983	0.200	0.12	636

The oxygen saturation of water (O_2 Saturation) is chosen to be a useful parameter because higher oxygen saturation contributes to better water quality and its content in water should be maximized (max), while other parameters need to participate with a lower share - minimized (min). The linear preference function was chosen as the preference function for all of the criteria because of the parameters' quantitative nature, with adopted thresholds of indifference and preference (Q and P) in the zones of 5% and 30%, respectively.

To define the weight criteria, the fact that not all of the parameters have the same impact on water quality is taken into account so the SWQI (*Serbian Water Quality Index*) share of each parameter in the overall water quality index for the year 2009 is used for such purposes. The SWQI method was discussed in greater detail in our previous paper (Takić et al, 2012).

Based on data from the ranking scenario (Table 1) the values of positive and negative flows were obtained, and PROMETHEE II performed a complete ranking of the selected locations from the aspect of the presence of harmful water quality parameters in the river on these locations, for the defined scenario.

The results show that the location with the best water quality is Dobra (L14), while the location with the worst water quality is Pančevo (L9).

The analysis results are graphically obtained within the GAIA plane and shown in Fig. 1. The measure of the quantity of information preserved by the defined model is satisfactory (Δ = 71.05 %) so the validity of using this graphic tool in further presentation of the results is quite reasonable. In practice, the value of Δ is usually around 60% and in some cases larger than 80% (Brans and Mareschal, 1994). The coordinate axes, presented in Fig. 1, are used for the segmentation of space in order to present the strengths of the alternatives and criterions better according to their position in the GAIA plane. These axes are dimensionless and used only for better graphical representation.

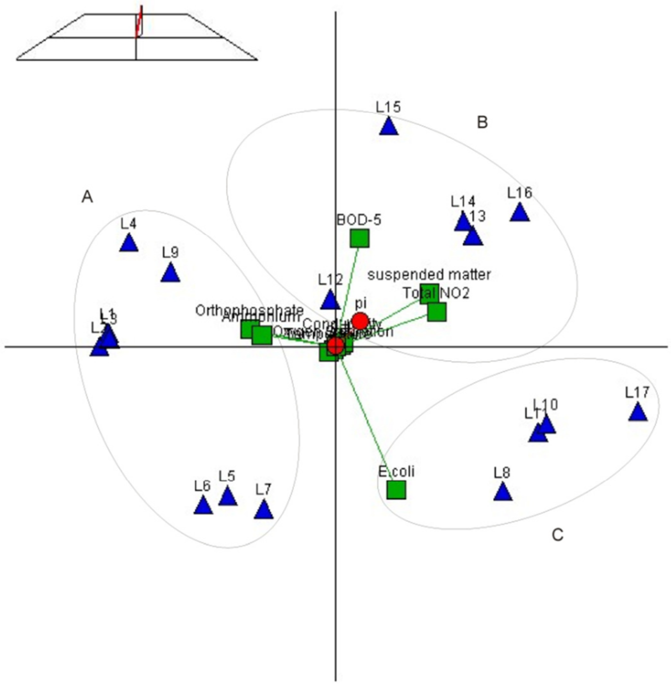

Fig. 1 GAIA plane for the defined Scenario

Locations in Fig. 1, gathered as Cluster B (L13, L14, L16 and L15) are good for a large number of criteria, as being closest to the decision stick *pi* which defines a compromising solution in accordance to the given weights of the criteria, and with the lowest concentrations of total nitrogen oxides, suspended matter and BOD-5, which contributes to good water quality. On the other hand, within Cluster A of Fig. 4, there are locations directed opposite to the decision stick (L9, L4, L1, L2 and L3) with the largest percent of harmful water quality parameters, which evidently are not good according to any criterion, and especially according to the suspended matter, total NO_2 and BOD-5. Cluster C (L8, L10, L11 and L17) brings together locations with the lowest concentrations of *E.coli* as a representative of micro-biological indicators of water quality. Parameters such as temperature, pH and conductivity are the criteria of the smallest impact on the ranking. They are located in the very beginning of the GAIA coordinate plane which indicates that they are neutral.

3. Conclusion

According to the results, better water quality was registered at the exit profile as opposed to the entry profile of the Danube in Serbia, indicating a significant role in the self-purification process of the river played by the Iron Gate at the exit part of the river from the country.

Pančevo (L9) is a place of potential environmental risk, so adequate measures for maintaining better water quality on this location should be taken in order to achieve and preserve better quality of water in this part of the Danube. One of the possible solutions is to create a wastewater treatment plant on this location and on all the other locations of potential environmental risk.

In order to improve the living environment, this work should stress the importance of preserving the quality of the Danube water. The results of the applied PROMETHEE/GAIA method can be used as a starting point for the implementation of adequate measures to repair the main pollutants in order to improve the quality of the Danube River on its course through Serbia.

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RANGIRANJE LOKACIJA POTENCIJALNOG EKOLOŠKOG RIZIKA NA DUNAVU

Rangiranje kvaliteta vode u ovom radu izvršeno je korišćenjem PROMETHEE/GAIA metode, na osnovu rezultata monitoringa sedamnaest mernih lokacija na Dunavu u 2009. godini. Za potrebe istraživanja posmatrano je deset parametara kvaliteta vode (elektroprovodljivost, pH, suspendovane materije, zasićenost vode kiseonikom, temperatura, ortofosfati, ukupni oksidi azota, biološka potrošnja kiseonika (BPK-5), amonijum jon i E.coli) koji predstavljaju kriterijum rangiranja lokacija na Dunavu. Lokacije su grupisane u klastere prema međusobnoj zavisnosti parametara. Rezultati PROMETHEE/GAIA analize rangiranja pokazuju da je najbolji kvalitet vode na lokaciji Dobra (L14), dok je najlošiji kvalitet vode na lokaciji Pančevo (L9). Smer zaključivanja ukazuje da je Pančevo (L9) lokacija potencijalnog ekološkog rizika koja zahteva sprovođenje adekvatnih mera zaštite u cilju postizanja i očuvanja boljeg kvaliteta vode na ovom delu Dunava.

Ključne reči: *Dunav, ekološki rizik, PROMETHEE/GAIA metoda, rangiranje*