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ASSESSMENT OF POLLUTION WITH TOXIC ELEMENTS IN RIVER SEDIMENTS BY CALCULATING FACTORS OF CONTAMINATION AND APPLICATION OF STATISTICAL METHODS

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Abstract: In order to effectively monitor the impact of polluted river sediments on the environment and human health, the information about the origin of toxic elements is very important (geochemical or anthropogenic), their variability and environmental risks associated with pollution. The research in this paper was conducted to assess and quantify contamination, as well as the assessment of risks from pollution with certain elements (As, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, V and Zn) in river sediments in Serbia. Assessment of contamination was performed by determining the total content of the elements and defining of background content in the sediment, as well as calculating the pollution indexes. Results of multivariate analysis indicate anthropogenic origin of Pb, Zn, Cd, As, Ni and Cu, while Fe, V, Mn, Co and Cr have mixed origin (lithogenic and anthropogenic sources). The most contaminated river systems are Ibar, Pek, Zapadna Morava (West Morava) and Velika Morava(Great Morava). The results show that in the basins of these rivers are important sources of heavy metals, mainly originating from industry and mining basins.

Keywords: *pollution, toxic elements, river sediments, pollution indices, statistical methods*

INTRODUCTION

Surface water sediments are most vulnerable to various forms of pollution, including trace elements due to their ease of access due to disposal

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of urban and industrial wastewater[4]. The sediments consist of inorganic and organic particles with complex physical, chemical and biological characteristics. They can scavenge some elements, thus acting as an adsorptive sink with metal concentrations many times greater than in the water column[5].

Metal contamination in surface sediments could directly affect the river water quality, resulting in potential consequences to the sensitive lowest levels of the food chain and ultimately to human health. In order to identify pollution problems, the anthropogenic contributions should be distinguished from the natural sources. Geochemical approaches such as the enrichment factor (EF) and geochemical index methods have been successfully used to estimate the impact of the activities of civilisation on sediments (Chabukdhara and Nema 2012).

In this study, the evaluation of the metal pollution level and possible sources compared to background pollution is performed for river sediments in Serbia. The main objectives were: (1) to determine the total content of As, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, V and Zn; (2) the calculation of theenrichment factor, index of geoaccumulation, ecological risk factor, potential ecological risk index, and pollution load indexto estimate the anthropogenic input of the elements and to assess the pollution status of the area; and (3) to identify the main sources of toxic elements.

1. MATERIAL AND METHODS

1.1. Study area

The largest and most important rivers that flow through Serbia are: the Danube, Sava, Great Morava, West Morava, South Morava, Tisa, Ibar, Drina, Timok, Nišava, Tamiš and Begej. The Danube is the most important and the second largest river in Europe, which flows through more countries than any other river in the world - Germany, Austria, Slovakia, Hungary, Croatia, Serbia, Romania, Bulgaria, Ukraine, and Moldova. On its way from the Black Forest (Germany) to its mouth in the Black Sea (Romania and Ukraine), the Danube River passes by or through ten riparian states, which makes it the most international river in the world. The major tributaries of the Danube River are: Drava, Sava and Drina rivers in the west, Morava in the south, Tisa, Tamiš, Moriš and Timok rivers in the north and east were the most important lines of communications.

The Sava River is the biggest tributary of the Danube River. Along its total length of 944 km and total catchment area of 97,713 km^2, the Sava River connects four countries and more than 8 million people who live in and from its catchment area.Tisa River is considered the largest tributary of Danube River by its total length of 977 kilometers. Tisa River's source is in Ukraine in the Western Carpathians where the Black Tisa at the altitude of 960 meters and White Tisa at the altitude of 1700 meters join. Tisa River flows through Ukraine, Slovakia, Romania, Hungary and Serbia.

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[4] Chabukdhara and Nema, 2012

[5] Kabir et al. 2011

1.2. Description of the sampling site and sampling

Cross border pollution indicates a need to determine the pollutants in the water and sediment in all the countries along the river's flow. Because of that, for this sake investigation 35 river sediment samples were taken from the main rivers in Serbia: the Danube (Black Sea watershed), the Sava (Danube watershed), the Tisa (Danube watershed), the Ibar (West Morava watershed), the Great Morava (Danube watershed), the West Morava (Great Morava watershed), the South Morava (Great Morava watershed), the Nišava (South Morava watershed), the Tamiš (Danube watershed), the DTD canal (Danube watershed), the Topčiderska River (Sava watershed), the Porečka River (Danube watershed), the Kolubara (Sava watershed), the Pek (Danube watershed) and the Toplica (South Morava watershed). For the larger rivers, sampling was conducted at several locations (Figure 1 and Table 1).

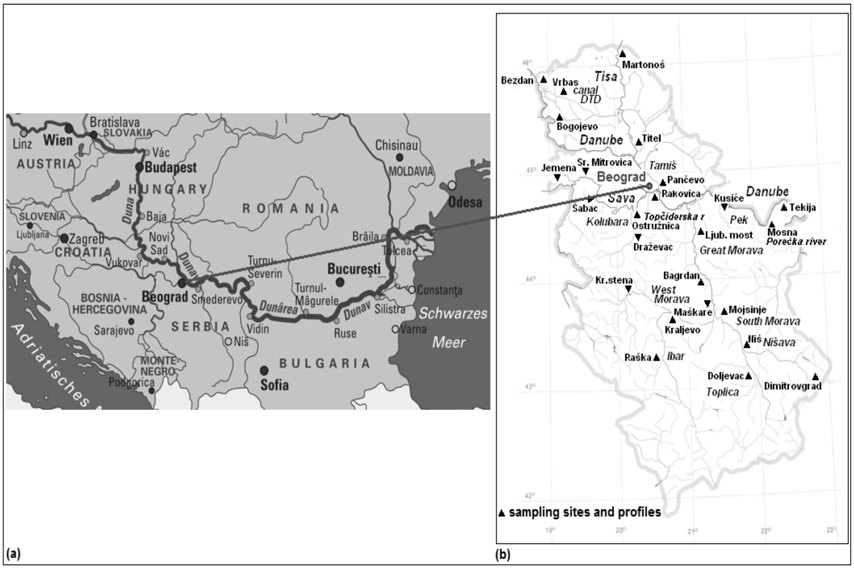

Figure 1.Danube watershade and sampling locations.

The sediment samples were stored at 4°C in order to prevent changes in the chemical composition of the sediments. The contents of the micro and macro-elements were determined in the granulometric fraction < 63 μm of the bottom sediment samples ("grab"- the sample) after air drying for 8 days[6].

1.3. Analytical procedures and element analysis

In this paper, the total content of elements in the sediments was determined by digestion with very strong acids: HNO_3+HCl+HF. Microwave digestion was performed in a pressurised microwave oven (Ethos 1, Advanced Microwave Digestion System, Milestone, Italy) equipped with a rotor holding 10 microwave vessels (PTFE).

[6] Sakan et al. 2011

Table 1.Sampling locations

River	Watershed	Sampling sites
Danube	Black Sea	D1–D6
Sava	Danube	S1–S4
Tisa	Danube	T1–T9
Ibar	West Morava	I1, I2
Great Morava	Danube	V1, V2
West Morava	Great Morava	Z1, Z2
South Morava	Great Morava	JM
Nišava	South Morava	N1, N2
Tamiš	Danube	Ta
DTD canal	Danube	DT
Topčiderska River	Sava	Tr
Porečka River	Danube	Pr
Kolubara	Sava	Ko
Pek	Danube	Pe
Toplica	South Morava	To

In this research, the following elements were determined in each sample: As, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, V and Zn. The obtained results in the manuscript are expressed in mg kg^{-1} dry sediment. The analytical determination of the studied elements was realised with an atomic emission spectrometer with an inductively coupled plasma iCAP-6500 Duo (Thermo Scientific, United Kingdom.

1.4. Assessment of sediment contamination

Various calculation methods for quantifying the degree of metal-enriched in sediments have been put forward. In this paper, different indices were used to assess the degree of trace element contamination in river sediments in Serbia: Enrichment factor (EF), Index of geoaccumulation (Igeo), Ecological risk factor (Er^i), Potential ecological risk index (RI), and Pollution load index (PLI).

Enrichment factor (EF): A common approach to estimate how much the sediment is impacted (naturally and anthropogenically) with heavy metal is to calculate the Enrichment Factor (EF) for metal concentrations above the un-contaminated background levels. The EF of a heavy metal in sediment can be calculated using the following formula:

$$EF = (M/Y)_{sample} / (M/Y)_{background},$$

where:

✓ *M* is the concentration of the potentially enriched element and

- Y is the concentration of the proxy element. Although EF is not a function of time in its mathematical expression, it reflects the status and degree of sediment pollution[7].

Index of geoaccumulation (I_{geo}): Index of geoaccumulation (I_{geo}), introduced by Müller[8], has been used widely to evaluate the degree of metal contamination or pollution in terrestrial, aquatic and marine environments. The I_{geo} of an element in sediment can be calculated with the formula[9]:

$$I_{geo} = \log_2[C_{metal} / 1.5\ C_{metal\ (control)}],$$

where:

- C_{metal} is the concentration of the heavy metal in the enriched sample
- $C_{metal(control)}$ is the concentration of the metal in the unpolluted sample or control.
- The factor 1.5 is introduced to minimise the effect of the possible variations in the background or control values, which may be attributed to lithogenic variations in the sediment[10].

Ecological risk factor (Er^i): An ecological risk factor is used to quantitatively express the potential ecological risk of a given contaminant also suggested by Hakanson (1980). This factor can be calculated with the formula:

$$Er^i = Tr^i \cdot C^i_f,$$

where:

- Tr^i is the toxic-response factor for a given substance (for Hg, Cd, As, Cr and Zn, they are 40, 30, 10, 2 and 1 respectively; and 5 for Pb, Cu and Ni[11], and
- C^i_f is the contamination factor.

Ecological risk index (RI): The potential ecological risk index (RI)[12] is defined as the summation of the change occurred in metals with respect to the background values considering the toxicological factor. The mathematical relation of RI can be shown as:

$$RI = \sum (T_i \times C_i/C_o),$$

where:

- T_i is the toxic-response factor for a given substance,
- C_i represents the metal content in the sediment and
- C_0 is the regional background value of heavy metals.

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[7] Ruzhong et al. 2010

[8] Müller, 1979

[9] Asaah and Abimbola, 2005; Mediola et. al 2008

[10] Mediola et al. 2008

[11] Yang et. al. 2009

[12] Hakanson, 1980; Yang et al, 2009

Pollution load index (PLI): Tomlinson et al.[13] introduced the concept of the PLI to assess metal pollution in sediment. The PLI for a single site is the *n*th root of the number (n) of multiple contamination factors (CF) multiplied together:

$$PLI = (CF_1 \times CF_2 \times CF_3 \times \ldots CF_n)^{1/n}.$$

This empirical index provides a simple, comparative mean for assessing the level of heavy metal pollution.

1.5. Statistical analysis

Multivariate analysis was performed using principal component analysis (PCA). The statistical analyses were conducted by using SPSS 11.0 andnormalized data set.

2. RESULTS AND DISCUSSION

2.1. Performance of the analytical procedure

The accuracy and precision of the obtained results were checked by analysing sediment reference material (BCR standards, 143R and 146R). The results indicate a good agreement between the certified and analytical values. The recovery of elements being practically complete for most of them and the values were in the acceptable range (recovery: 80-120%)[14]. The precision is expressed as relative standard deviations. The relative standard deviations of the means of duplicate measurement were less than 4% (from 0.03 to 3.80%) for all the measured elements.

2.2. Descriptive statistics of elements contents in sediments

Basic statistics (minimum and maximum, as well as the means and standard deviations) for the total contents of all the measured elements in the investigated river sediments are shown in Table 2. The order of the total element content was Zn > Cu > Pb > Ni > Cr > V > Co > Cd > As (not taking into account Fe and Mn). Some of heavy metals showed significant spatial variations, suggesting there is no uniform distribution of those heavy metals.

Table 2. Total contents of elements in different river sediments, this study (mg kg^{-1})

	As	**Cd**	**Co**	**Cr**	**Cu**	**Fe**	**Mn**	**Ni**	**Pb**	**V**	**Zn**
Min	0.29	1.28	8.22	59.8	11.5	24556	648	33.2	57.8	60.4	66.6
Max	8.89	10.5	36.2	230	870	62800	3688	274	318	149	1095
Mean	1.42	4.82	21.97	113	78.5	44177	1399	77.8	132	111	353
SD	1.44	2.08	6.63	41.0	141	7200	556	58.5	51.0	18.4	232
Median	0.80	4.69	21.5	102	47.9	45780	1352	46.3	124	111	330

[13] Tomlinson et al. 1980

[14] Chang et al. 2009

2.3. Calculating the grade of contamination and risk category

Contamination of the investigated river sediments with the studied trace elements was assessed using: EF, I_{geo}, Er, RI, and PLI. Table 3 and Table 4 show the grades of contamination and ecological risk based on the calculated factors. On the base of the pollution load index, contamination of sediment can be classified as: pollution exists, when the PLI > 1, and no metal pollution, if the PLI < 1[15].

The element content in the DTD canal (station in Vrbas) were chosen as the background values for elements in this research because there are no significant anthropogenic sources of toxic elements at this locality and the sediment samples are similar to the other investigated river sediments of geochemical characteristics and composition. Background elements values in this research are (in mg kg^{-1}): 1.28 (Cd), 11.5 (Cu), 8.22 (Co), 648 (Mn), 62.1 (Cr), 34.7 (Ni), 57.8 (Pb), 66.6 (Zn), 60.4 (V), 245556 (Fe) and 360323 (Al). For the background value of As, the content of the continental crust used is: 1.7 mg kg^{-1}[16].

Table 3. Grades of Enrichment factor and Index of geoaccumulation

Enrichment factor (**EF**)		Index of geoaccumulation (**I_{geo}**)	
Value	Pollution category	Value	Pollution category
EF <1	No enrichment	Igeo < 0	uncontaminated/ unpolluted (*class 0*)
1 ≤ EF ≤ 3	Minor	0 ≤ Igeo < 1	unpolluted/ moderately (*class 1*)
3 ≤ EF ≤ 5	Moderate	1 ≤ Igeo < 2	moderately (*class 2*)
5 ≤ EF ≤ 10	Moderately severe	2 ≤ Igeo < 3	moderately/ heavily (*class 3*)
10 ≤ EF ≤ 25	Severe	3 ≤ Igeo < 4	heavily (*class 4*)
25 ≤ EF ≤ 50	Very severe	4 ≤ Igeo < 5	heavily/ extremely (*class 5*)
EF >50	Extremely severe	Igeo ≥ 5	extremely (*class 6*)

The sediment normalization element is aluminum. This element was chosen because Al is a conservative element and a major constituent of clay minerals, and has been successfully used in previous investigations[17].

Table 4. Grades of Ecological risk factorand Ecological risk index

Ecological risk factor (**Er**)		Ecological risk index (**RI**)	
Value	Risk category	Value	Risk category
Er< 40	Low	RI < 150	Low risk
40 ≤Er < 80	Moderate	150 ≤ RI < 300	Moderate
80 ≤ Er < 160	Considerable	300 ≤ RI< 600	Considerable
160 ≤Er < 320	High	RI ≥ 600	Very high
Er ≥ 320	Very high	/	/

[15] Varol 2011

[16] Wedepohl 1995

[17] Rubio et al. 2000

The content all of elements were higher than the background values for the investigated elements.

Enrichment factor (EF)

The EF values were interpreted as suggested by Acevedo-Figueroa et al. (2006) (Table 3) and were calculated separately for all the sampling sites (Figure 2a). River sediments in Serbia showed a wide range of trace element enrichment. In general, the order of the average EF values was Cu > Zn > Cd > Co > Pb > Ni > Mn > Cr > As. According to the categories, these findings indicate that Cu, Zn and Cd enrichment was high. From the point of view regardingpollution, the EF of Cu in the river Pek (35.03) were the highest among the elements of the investigated sediments, suggesting significant contamination at this locality. There is also a significant anthropogenic contribution to the elements in the sediments, mainly from the Ibar (I1, I2), Great Morava (V1), West Morava (Z1) and Tisa (T7).

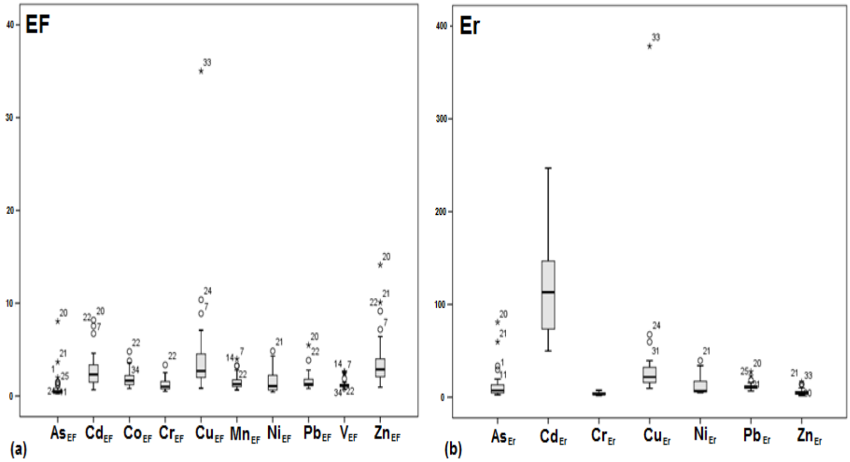

Figure 2. Values of EF (a) and Er (b) for studied elements.

Ecological risk factor (Er^i)

The ecological risk assessment results are summarised in Figure2b. The potential ecological risk factor for the individual element values varied depending on the studied elements in the sediments, as well as in different areas. These results indicated that the river sediments posed a low to high potential of ecological risk.

The potential ecological risk indices of Cr, Ni, Pb, Zn and As were lower than 40 (except for arsenic at two locations in the IbarRiver), which indicates a slight potential of ecological risk of these elements in the main Serbian river. Among the studied elements, Cd and Cu present a higher ecological risk than any other elementbecause of their higher toxic coefficient. The average ecological risk of Cd was over 80, indicating that Cd posed a considerable risk to local environment. The highest Er value is observed for Cu in the Pek River sediment, which indicates a very high potential of ecological risk at this locality.

Index of geoaccumulation (I_{geo})

Müller (1979) proposed seven grades or classes based on the increasing numerical value of the I_{geo} index (Table 3). The greatest number of samples and elements belong to Class 1 (Figure 3), i.e. unpolluted to moderately polluted sediment (with As, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb and V). Class 2 (Cd, Cu, Zn, Cd and Pb in some samples), Class 3 (Cu in the river Pek and the West Morava 1, and Zn in the Ibar 1 and Ibar 2 and Pek) and the largest I_{geo} value - 3.92 in sediment from the Pek River for Cu (Class 4, heavy pollution).

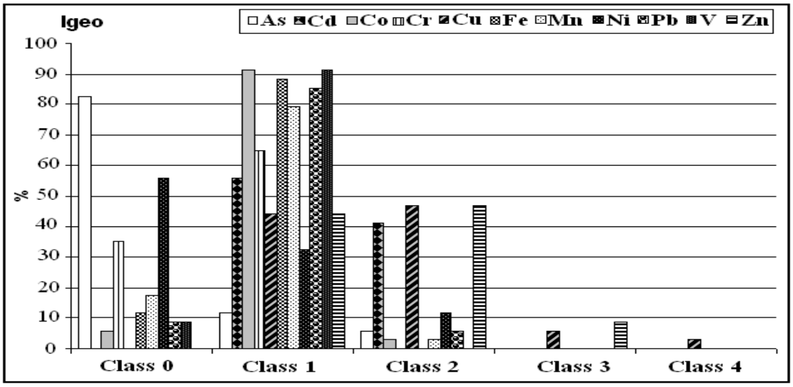

Figure 3. Igeo values for studied elements.

These findings indicate that the primary rivers contaminants are Cu and Zn, as well as Cd. These results are consistent with EF values. The negative Igeo values, mainly for As, Cr, and Ni result from the relatively low levels of contamination in some sediment samples.

Ecological risk index (RI)

The RI was calculated as the sum of all the calculated risk factors. The contamination categories on the basis of ecological risk are presented in Table 4 and Figure 4.

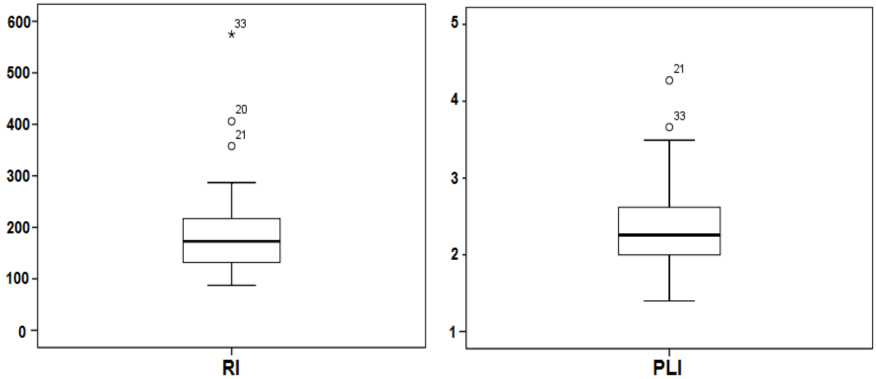

Figure 4. RI and PLI in river sediments.

The potential RI values in the surface sediments are generally lower than 300, suggesting that sediment samples from the river catchments exhibited low and moderate ecological risk for the investigated elements. However, in three (two sediment samples from the Ibar and one from the Pek River) out of 34 samples of sediments had RI values (from 300 to 600), which indicates a high ecological risk of heavy metals

The contribution percent of the individual element to the overall potential ecological risk revealed that the most toxic element, Cd, is the main contributor to the totallypotential ecological risk. Because Cd pollution, in general, was the result of a long history of accumulation, there is a strong potential risks to the ecosystem and the health of the residents in this region[18].

Pollution load index (PLI)

Figure 4 represents the PLI values of the studied elements. The PLI values varied from 1.4 to 4.27 for the investigated sediments, suggesting that pollution exists. The highest PLI values were observed in the following sediments: 4.27 (Ibar), 3.66 (Pek), 3.49 (West Morava) and 3.33 (Great Morava). Since the PLI values are greater than 3, it can be concluded that the studied river systems are significantly polluted (indicating an extremely high toxic element content in the sediment).High PLI values, but lower than 3, are observed in the following sediments: Tisa River (PLI from 2.00 do 2.67); Sava River (PLI values about 2.20) and Great Morava River (PLI value about 2.86). Other sites with a PLI between 1 and 2 can be classified as moderately polluted.

2.4. Trace elements and sample site grouping using principal component analysis (PCA)

A PCA with Varimax normalised rotation was performed in this research. The scores and loadings of the principal components are presented in Table 5 and Figure 5. PC1, explaining 60.86 % of the total variance, has strong positive loadings for Fe, Mn, Co, Cr and V. PC2, explaining 15.67 % of the total variance, has strong loadings for As, Pb, Zn, Cd and Ni. PC3, explaining 10.58 % of the total variance, has a strong positive loading on Cu.

Table 5. Loadings of experimental variables

	PC1	PC2	PC3
As		0.906	
Fe	0.933		
Mn	0.778		
Co	0.933		
Cr	0.862		
Pb	0.590	0.720	
Zn		0.774	

[18] Gao et al. 2013

Cd	0.596	0.624	
Ni	0.579	0.630	
Cu			0.893
V	0.911		
Eigenvalue	6.694	1.724	1.164
% Total variance	60.855	15.669	10.578
Cumulative % variance	60.855	76.525	87.103

Obtained results indicate that elements with similar origins are: (1) Fe, V, Mn, Co and Cr; (2) Pb, Zn, Cd, As and Ni and (3) Cu. It is observed that the sources of Cu are different from the other elements (R mode, PCA; Figure 5a).

Fe, V, Mn, Co and Cr have a combined source and these elements are derived from lithogenic and anthropogenic sources. Iron is abundant in the Earth's crust, though the pollution indicates the existence of anthropogenic sources of this element at some localities. Also, enrichment is observed for Mn in some of sediments. Cr is generally a sign of the paint and metal industries, V is greatly impacted by anthropogenic activities such as mining and agricultural processes, and Co is mainly from anthropogenic signatures, i.e., paint, fertiliser or agrochemical industries. The low content of V, Co and Cr in the investigated sediments and the values of the calculated pollution indices, which indicate insignificant pollution, confirmation of the mixed sources of Fe, V, Mn, Co and Cr at the studied locality.

Pb, Zn, Cd, As and Ni are mainly derived from anthropogenic sources. The significant anthropogenic source of these elements are mining and smelting complexes in Serbia. Trepča mining complex is the dominant source of lead and zinc. In addition to mining, anthropogenic sources of these elements may be directly discharged from locally based sources, such as industrial and urban discharges carrying metal and metalloid contaminants. Contaminants mainly come from metallurgy and coal burning. Fertiliser and pesticides containing As can also lead to an increase of As. Ni is also mainly derived from anthropogenic activities, especially from industrial sources.

Cu is derived from anthropogenic sources, most significantly from metallic wastewater discharges. The significant anthropogenic source of Cu is the open-pit mine in Majdanpek. Another source of Cu may be discharges from industries, as well as agricultural activities.

Figure 5b displays isolated three groups of samples: 20 (I1), 21 (I2), 22 (V1), 23 (V2) and 25 (Z2) - first group, 33 (Pe) - second group, and the other sediment samples constitute the third group. These are the results of the application of the PCA (Q mode). Sampling site 33 (Pek River) has the most polluted river sediments at the investigated localities. The contribution of Cu to the overall pollution is the most significant, compared to other elements in this sediment. In the group with sediments 20, 21, 23 and 25 is the sediment sample with significant pollution compared to other moderately polluted studied sediments.

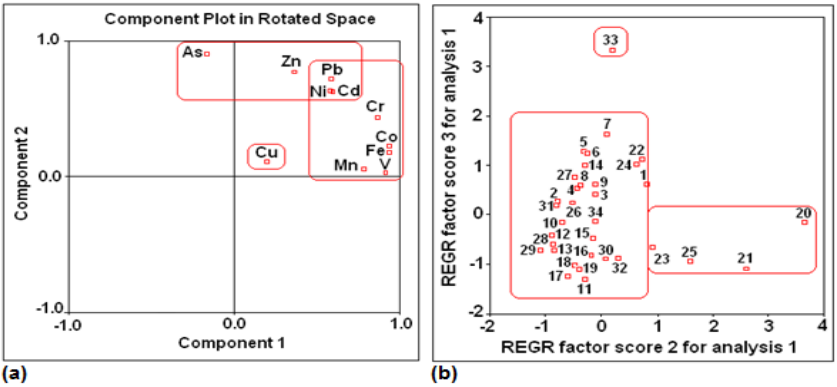

Figure 5. Results of PCA analysis.

The results in this manuscript indicate that the most polluted sediments at the studied localities are sediments from the Ibar and Pek Rivers. Besides these two rivers, the Great Morava and West Morava are also significantly polluted river systems. Pollution of these rivers is mainly caused by permanent and accidental pollution from industrial plants and mines that are located in the basins of these rivers. One of the main industrial polluters of the Ibar River is Trepča mining complex. This huge industrial mining site has been in operation and engaged in large-scale exploitation since 1925. Since then, and until the year 2000, lead and zinc has been mined and smelted and the tailings still threaten the environment and continue polluting the Ibar River[19].

The significant pollution with Cu of sediments from the Pek River is generally related to the Cu mining complex in Majdanpek. The copper ore treatment process produces large amounts of ore waste and flotation tailing heaps, located in the vicinity of Bor and Majdanpektowns. In addition to permanent pollution, the accidental pollution significantly affects the pollution of the Pek River. The most serious incidents are the breaches of tailing dams at Majdanpek and Veliki Majdan causing direct and serious contamination of the Pek River by heavy metals.

In general, the results obtained using multivariate statistical analysis are consistent with the results obtained using the calculation of pollution indices. Rivers of the same category have the same source of pollution and a similar degree of contamination. The applied methods can classify sediments in the whole investigated region according to the degree of pollution and to identify the main sources of toxic elements.

CONCLUSION

The impact of trace element pollution on the quality of the river sediments in Serbia was evaluated using different pollution indices. The source identification carried out using multivariate analyses shows that: (1) Fe, V, Mn, Co and Cr are derived from lithogenic and anthropogenic sources, (2) Pb, Zn, Cd, As, and Ni are mainly derived from anthropogenic sources, and (3) Cu

[19] Rank and Klemmensen, 2003

is derived from anthropogenic sources, most significantly from metallic wastewater discharges.

Contamination was observed in the studied elements, most of all with Zn, Cu and Cd. Cd and Cu present a higher ecological risk than any other element because of their higher toxicity coefficient. The potential ecological risk factors varied among the studied elements in the sediments as well as in the different areas. The values of the pollution load index suggests that the degree of contamination ranges from low to very high. The highest values of the pollution indices suggest a significant contribution of elements from anthropogenic sources in the river sediments from the Ibar, Pek, West Morava and Great Morava Rivers. Significant pollution indexes are also observed in the Tisa and Sava Rivers. Pollution of these rivers is mainly caused by permanent and accidental pollution from industrial plants and mines that are located in the basins of these rivers. Significant influences are evident from mining complexes (mainly in Trepča and Majdanpek) on river contamination with toxic trace elements.

The above results confirmed the existence of pollution with trace elements in the studied river sediments. The calculated pollution indices and the appliance of statistical methods are recognised as useful for improving ecological risk assessment and the management of trace elements in sediments.

Acknowledgments

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PROCENA ZAGAĐENJA REČNIH SEDIMENATA TOKSIČNIM ELEMENTIMA PRIMENOM FAKTORA KONTAMINACIJE I STATISTIČKIH METODA

Dr Sanja Sakan, dr Dragana Đorđević, doc. dr Nenad Sakan

Apstrakt: Da bi se mogao pratiti uticaj zagađenog rečnog sedimenta na životnu sredinu i zdravlje ljudi veoma su važne informacije o poreklu toksičnih elemenata (geohemijsko ili antropogeno), njihovoj varijabilnosti i potencijalnom ekološkom riziku. Istraživanje u ovom radu je sprovedeno sa ciljem procene i kvantifikovanja kontaminacije, kao i procene rizika od zagađenja određenim elementima (As, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, V i Zn) u rečnim sedimentima u Srbiji. Procena kontaminacije je izvedena određivanjem ukupnog sadržajai definisanjemfonskog sadržaja elemenata u sedimentu, kao i računanjem faktora kontaminacije. Rezultati primene statističkih metoda ukazuju na antropogeno poreklo Pb, Zn, Cd, As, Ni i Cu, dok su Fe, V, Mn, Co i Cr mešovitog porekla (litogeni i antropogeni izvori). Najviše kontaminirani rečni sistemi su Ibar, Pek, Zapadna Morava i Velika Morava. Rezultati pokazuju da u slivovima ovih reka postoje značajni izvori teških metala, uglavnom industrija i rudarski baseni.

Ključne reči: *zagađenje, toksični elementi, rečni sediment, faktori kontaminacije, statističke metode*

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