Original Research

Comparative Review of Sediment Properties from Drainage Canals

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Abstract

Our paper presents a comparative review of the properties of sediments from drainage canals in Backa and Banat (two regions in northern Serbia). The drainage canals are important for agriculture and water management in the two regions. On the other hand, these canals are exposed to different point and non-point polluters. The resulting accumulation and increased concentration of undesirable substances in sediments may adversely impact the environment in the canals and their surroundings.

Thirty-nine samples of canal sediments were collected in each region. The samples were analyzed for concentrations of macronutrients and heavy metals. The content of nutrients was on average 2 to 2.5 times higher in drainage canal sediments than in the arable soil around the canals. The average concentrations of heavy metals in the sediments were 38.84 and 53.75 $mg \cdot kg^{-1}$ for Pb; 2.79 and 7.55 $mg \cdot kg^{-1}$ for Cd; 52.09 and 42.72 $mg \cdot kg^{-1}$ for Ni; 28.73 and 698.36 $mg \cdot kg^{-1}$ for Cr; 40.76 and 13.54 $mg \cdot kg^{-1}$ for As; 60.32 and 52.33 $mg \cdot kg^{-1}$ for Cu; and 200.10 and 222.94 $mg \cdot kg^{-1}$ for Zn, for Backa and Banat, respectively. The sediments of studied canals were characterizied by high concentrations of heavy metals, in some of them several times exceeding the allowable maximum concentration. These canals were typically located near large urban areas, directly receiving untreated municipal and industrial waste waters in addition to drainage water. Judging by the number, type and intensity of pollution, the concentrations of nutrients and most of the analyzed heavy metals were higher in the canal sediments from Banat than those from Backa.

Keywords: canal, drainage, sediment, nutrients, heavy metals

Introduction

The main task of the drainage canals is to remove excess surface and ground waters to create favorable conditions for unhindered agricultural production and other activities in the regions of Backa and Banat (Vojvodina, northern part of Serbia). As the canals are mostly surrounded by arable land and numerous urban areas located within their catchment areas, they are affected by different processes and activities such as erosion in the catchment area and the canals themselves, crop residues, influxes of surface and ground waters and pesticides and fertilizers used in agriculture, direct discharge of industrial and municipal wastewaters into canals, etc. [1-3]. Because of the effects of point and nonpoint pollution sources on the one hand, and the flow characteristics of water, small longitudinal gradients, a low flow rate of water, a low transport capacity of water and bedload, and a number of other factors on the other, sediments are formed and deposited

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in the analyzed canals. Due to the large amounts of sludge deposited in some canal sections, its physical, chemical and biological characteristics have to be taken into account. Increased concentrations of nutrients and some hazardous and harmful substances in the sediments [4, 5], as well as subsequent interactive and degradative processes taking place in water and sediments, can cause extremely adverse effects (toxic, pathogenic, carcinogenic, mutagenic, etc.) in canals, along their banks [6], and in the locations where sediments are deposited or spread after maintenance dredging of the canal network. In addition to the agronomic, hydraulic, and economic aspects of the above problems, their ecological aspect is coming into focus [2, 4]. The importance and impact of sediments on aquatic ecosystems and the environment have been discussed by many researchers [7-15]. Some researchers pointed out certain problems associated with these issues, primarily those concerning respective legislation [16-19].

The paper presents a comparative overview and analysis of the characteristics of sediments from select drainage canals in the regions of Backa and Banat. The objectives of the study were to determine the characteristics of sediments in the selected drainage canals and to evaluate and compare the possible adverse effects of substances identified in the sediments on the environment in the two regions. Another objective was to call attention to the complex problem that sediments present to the drainage systems in the studied regions, whose impact on local water resources, agriculture, and the environment can produce far-reaching consequences. Emphasis was placed on the contents of nutrients and heavy metals in canal sediments.

Material and Method

Study Area

Backa and Banat are two adjacent regions in northern Serbia. They are located between 44º39' and 46º11' N geographic latitude and 18º51'and 21º33' E geographic longitude. The Tisza River makes a natural boundary between them. In this part of its course, the river flows approximately in the direction north-south (Fig. 1). The area of Backa is about 724,000 ha and that of Banat around 830,000 ha. Both regions are typically flat and about 85% agricultural land [20]. Due to the natural features and prevalent methods of land use, the regions periodically suffer from excess surface and ground waters. Drainage systems have been constructed for the collection and evacuation of excess water. Backa has 120 drainage systems with a total canal network length of about 6,600 km (9.1 $m \cdot ha^{-1}$). Banat has 130 systems with about 9,400 km of canals (11.3 $m \cdot ha^{-1}$) [21, 22]. The average size of individual drainage systems in both areas is slightly over 6,000 ha. Within these systems, sub-basins can be distinguished from which water gravitates toward certain drainage canals. The areas of these sub-basins are much smaller compared with the systems, but each of them can be considered a separate catchment area possessing specific characteristics and features. The total amount of sediments that has to be dredged up from the drainage canals during their regular maintenance is about $2 \cdot 10^6$ m^3 [1].

A larger part of the catchment areas of the above-described canals is arable land from which excess water carries sediments and various substances to the canals. Some canal sections pass through the outskirts of urban areas or

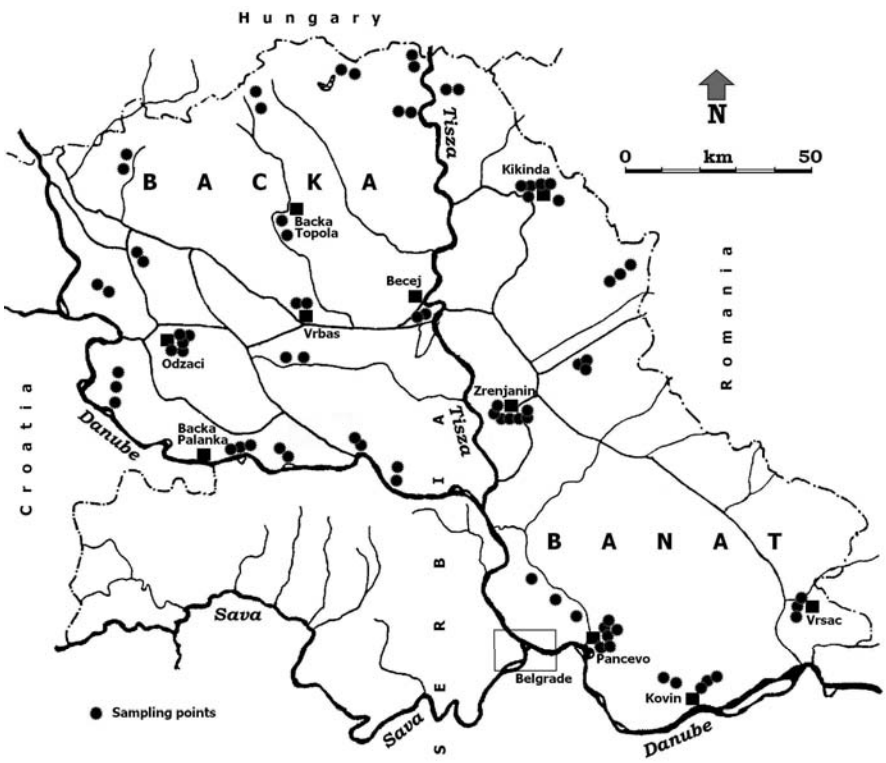

Fig. 1. Map of study area – sampling points.

through industrial zones from which they collect surface runoff and underground water as well as the untreated municipal and industrial wastewater. In other words, this study included canals that were exposed in large measure to the influences of surface runoff and directly discharged untreated wastewater. The analyzed canals belong to the network of local drainage systems. Most of the canals are small, with the flow rate of 1 $m^3 \cdot s^{-1}$, nevetheless the study area also included canals with flow rates of up to 3 $m^3 \cdot s^{-1}$.

Sampling

Within the framework of a multi-year study conducted 2004 to 2009, sediment sampling was performed in some 40 drainage canals, which had been considered as typical for the regions of Backa and Banat. Two samples were usually taken from each canal under consideration, i.e. a total of eighty samples. Equal numbers of samples were taken in both regions.

All sediment samples were collected from the bottom of the canals in disturbed state and then analyzed in the accredited (SRPS ISO/IEC 17025) soil laboratory of the Institute of Field and Vegetable Crops in Novi Sad, Serbia. The laboratory analyses covered the characteristics relevant for quality evaluation and classification of sediments: basic chemical properties and heavy metals content.

Nutrients and Heavy Metals Analysis

Total nitrogen in the sediment samples was determined with a CHNS analyzer, automatic method – AOAC Method 972.43 [23].

Available phosphorus (extraction with ammonium lactate) – AL method; phosphorus content by the blue method in a spectrophotometer Cary 3 E – Varian [24].

Available potassium (extraction with ammonium lactate) – AL method; potassium content determined flame photometrically EVANS [24].

We analyzed the concentrations of seven elements from heavy metals group (Pb, Cd, Ni, Cr, As, Cu, Zn).

Total heavy metal concentrations in sediment samples were determined by microwave-assisted digestion in accordance with USEPA Method 3051A [25] using the Milestone Ethos 1 microwave sample preparation system. Analysis was subsequently performed using ICP-OES (Varian Vista Pro-axial). Quality control was periodically carried out with IRMM BCR reference materials CRM-141R and CRM-142R. Recoveries were within ±10% of the certified values.

Potential toxicity due to possible excess concentrations of heavy metals was assessed according to the criteria and referent values stipulated in regulations on permitted amounts of hazardous and harmful substances in soil [26].

Results and Discussion

The characteristics described above are usually taken into account in classification of sediments and they describe the sediment impact on the environment, possibilities of sediment distribution in the environment, etc. This paper deals with the content of nutrients and heavy/trace metals in the analyzed sediments.

Nutrients

Based on the concentration of macronutrients: nitrogen – N (%), phosphorus – P_2O_5 (mg $100g^{-1}$), and potassium – K_2O (mg $100g^{-1}$), the canal sediments were classified in accordance with the agronomic criteria applicable to arable soil. Also, the content of nutrients in the sediments was compared against their content in the best agricultural soil in Backa and Banat, such as the chernozem soil, etc.

Concentration of nutrients in the analyzed canal sediments ranged widely, as might be expected in view of the diversity of the sediments regarding the processes of their formation, their origin, and the natural and anthropogenic influences to which they were exposed [5]. The average contents of macronutrients in the sediments from drainage canals in the regions of Backa and Banat were found to exceed the values typical for highly fertile arable soil in these regions. This finding confirmed the previous observation of processes of accumulation taking place and increasing the concentrations of various substances in the analyzed sediments. The average content of nitrogen in the most productive soils of Backa and Banat is about 0.2% [27, 28], while the average concentrations in the canal sediments from Backa and Banat were 0.39% and 0.49%, respectively. The average content of P_2O_5 is about 22 mg $100g^{-1}$ in the soil [27, 28], and the values in the sediments from Backa and Banat were 39.6 mg $100g^{-1}$ and 51.8 mg $100g^{-1}$, respectively. The average content of K_2O is about 22.5 mg $100g^{-1}$ in the soil [27, 28], and the average values in the sediments from Backa and Banat were 28.1 mg $100g^{-1}$ and 48.8 mg $100g^{-1}$, respectively (Fig. 2). The highest nitrogen concentrations found in the sediments were more than 7 times higher than those in the chernozem soil, while the difference between the average values was about 2.5 times. The highest concentrations of phosphorus and potassium in the sediments were 10 and 15 times higher, respectively, than in the soil. The differences between the average values for the two nutrients ranged between 2 and 2.5 times.

The comparative analysis of the characteristics of canal sediments indicated that differences existed in nutrient concentrations in the two regions. The differences were considerable in the case of average values and even higher in the case of maximum values. Basic statistical data and the significance of differences in nutrient concentrations in canal sediments from the two regions are shown in Table 1. It was evident that the concentrations of all nutrients were higher in the samples from Banat than those from Backa. The differences in the concentrations of potassium were statistically significant (Student *t*-test differences in means between the two groups) (Table 1).

Estimation made on the basis of the nitrogen content showed that 58.5% of the samples of canal sediments from

Table 1. Characteristic values of nutrient concentrations in sediments of drainage canals in Backa and Banat.

Parameter	N	P_2O_5	K_2O
Backa			
Min	0.07	4.30	3.50
Max	1.14	111.50	118.00
Mean	0.39	39.62	28.11
SD	0.31	33.20	24.19
Banat			
Min	0.06	4.30	8.18
Max	1.22	265.50	382.00
Mean	0.47	52.00	48.83
SD	0.31	51.31	67.35
t-test	-1.13	-1.27	-1.81*

*statistically significant at the $P<0.05$ level

Backa could be classified as well-provided, 36.6% as medium provided, and 4.9% as low in nitrogen. The respective values for the canal sediments from Banat were 79.4%, 11.8%, and 8.8% (Fig. 2a).

Estimations made on the basis of the phosphorus content showed the increased loads found in the samples from Banat, wherein 73.5% of the samples had a high P_2O_5 content and 11.8% had a medium content. The respective values for the samples from Backa were 53% and 26.8% (Fig. 2b).

The canal sediments from Banat also were found to have a significantly higher quantity of accumulated potassium than the sediments from Backa. As much as 97.1% of the samples from the former region were in the classes of high and medium K_2O, while the corresponding percentage of samples from the latter region was 78.1% (Fig. 2c).

Sediments typically accumulate in water bodies as a result of erosion processes. In the case of this study, it can be stated that the role of erosion in the transport of nonpoint pollutants from the surrounding agricultural land to drainage canals is exceedingly important for the properties of canal sediments. It should be mentioned that extreme contents of nutrients were found in the sediments of the canals which, in addition to nonpoint pollution (primarily by fertilizers contained in the runoff from arable land), were subjected to point pollution, or more specifically to direct discharge of untreated wastewater from urban areas, industrial facilities, and agricultural farms.

In both Backa and Banat canals, the highest concentrations of nutrients were found in canals running near large urban areas and directly receiving untreated municipal and industrial waste waters. These canals were in most cases exposed to combined effects of several polluters, but individual effects of these polluters were not considered in this paper. In Backa, those were canals near Backa Topola (1.14% N and 111.5 mg $100g^{-1}$ P_2O_5 in sediments - the canal receives waste waters from the urban zone, a meat processing facility and an animal feed plant), Backa Palanka (1.14 and 1.07% N, 97.0 mg $100g^{-1}$ P_2O_5 and 68.0 mg 100 g^{-1} of K_2O – a beer brewery and a softdrinks factory), Odzaci (0.94%, 0.82%, and 0.79% N, 100.0 and 91.0 mg $100g^{-1}$ P_2O_5 and 87.9 mg 100 g^{-1} of K_2O – waste waters from the urban zone, a milk processing plant, chemical industry, a tannery), etc. In Banat, extremely high nutrient concentrations were found in canals near Pancevo (1.22, 1.12, 0.99% N, 265.5 and 58.3 mg $100g^{-1}$ P_2O_5 and 382.0 and 107.0 mg $100g^{-1}$ K_2O – waste waters from the urban zone, a chicken farm, a tannery, metal and glass industries, etc.), Zrenjanin (1.04 and 0.89% N, 183.0 and 84.6 mg $100g^{-1}$ P_2O_5 and 79.5 mg 100 g^{-1} of K_2O – waste waters from the urban zone, a sugar refinery, an oil refinery, a tannery, chemical and metal industries, etc.), Kikinda (1.04% N – waste waters from the urban zone, a brickyard, a foundry, a metal industry), Kovin (170.5 and 107.0 mg $100g^{-1}$ K_2O – an alcohol distillery), etc.

The concentrations of nutrients in the analyzed regions of Backa and Banat are the consequence of hydrotechnical conditions in the canals, but they depend primarily on land use methods applied in the catchment area, number and type of polluters, intensity of their activities, period of accumulation of sediments, the date of the last dredging, etc. It also is important to take into account the location of urban areas and industrial facilities and their proximity to rivers, main canals, or other water bodies, which can be more available recipients of waste waters than drainage canals.

Heavy Metals

Heavy metals are most important among the toxic substances found in the sediments at the bottom of drainage canals in Backa and Banat. Excess concentrations of heavy metals occur in canal sediments more frequently than the other harmful substances. Their presence in sediments may be due to natural causes, but they are more frequently present due to human activity. Increased concentrations of heavy metals are dangerous for the immediate surroundings of the canals as well as for the wider environment. Undesirable effects can be instantaneous (as soon as heavy metals reach canal water), or cumulative, arising from the buildup of these substances in the sediments, then plants and further along the food chain. The elements from this group are extremely persistent, and they also are potentially toxic, carcinogenic, mutagenic, etc. Furthermore, according to various criteria, heavy metals are the most common and most significant limiting factor in the analysis of possible adverse effects on the environment in the canals themselves, and especially when contaminated sediments are planned to be applied over the surrounding farmland [1, 2].

In addition to the comparative analysis of sediments from drainage canals in Backa and Banat, the contents of heavy metals also were compared against their maximum allowable concentrations (MACs) specified in Regulations on permitted amounts of hazardous and harmful substances in soil [26]. The maximum allowable concentration of heavy metals specified by regulations are in agreement with or somewhat higher than the limit values given in similar regulations and classifications from other countries [16-19]. The range from minimum to maximum concentrations of heavy metals in the samples of canal sediments from Backa and Banat as related with the MACs is shown in Fig. 3. The figure also gives the actual number and percentages of the samples containing excess concentrations of certain heavy metals as related to the total number of samples taken.

Lead (Pb)

All lead compounds are toxic. Increased lead levels may be expected around some industrial plants, heavily trafficked roads, in sewage sludge, etc. [29-31]. Increased lead concentration (253 mg·kg^{-1}) was found in only one sediment sample from Backa (the canal near Odzaci, which receives waste waters from the urban zone, chemical industry, a tannery, and a milk processing facility). Regarding the samples from Banat, 5 samples (12.8% of the total samples)

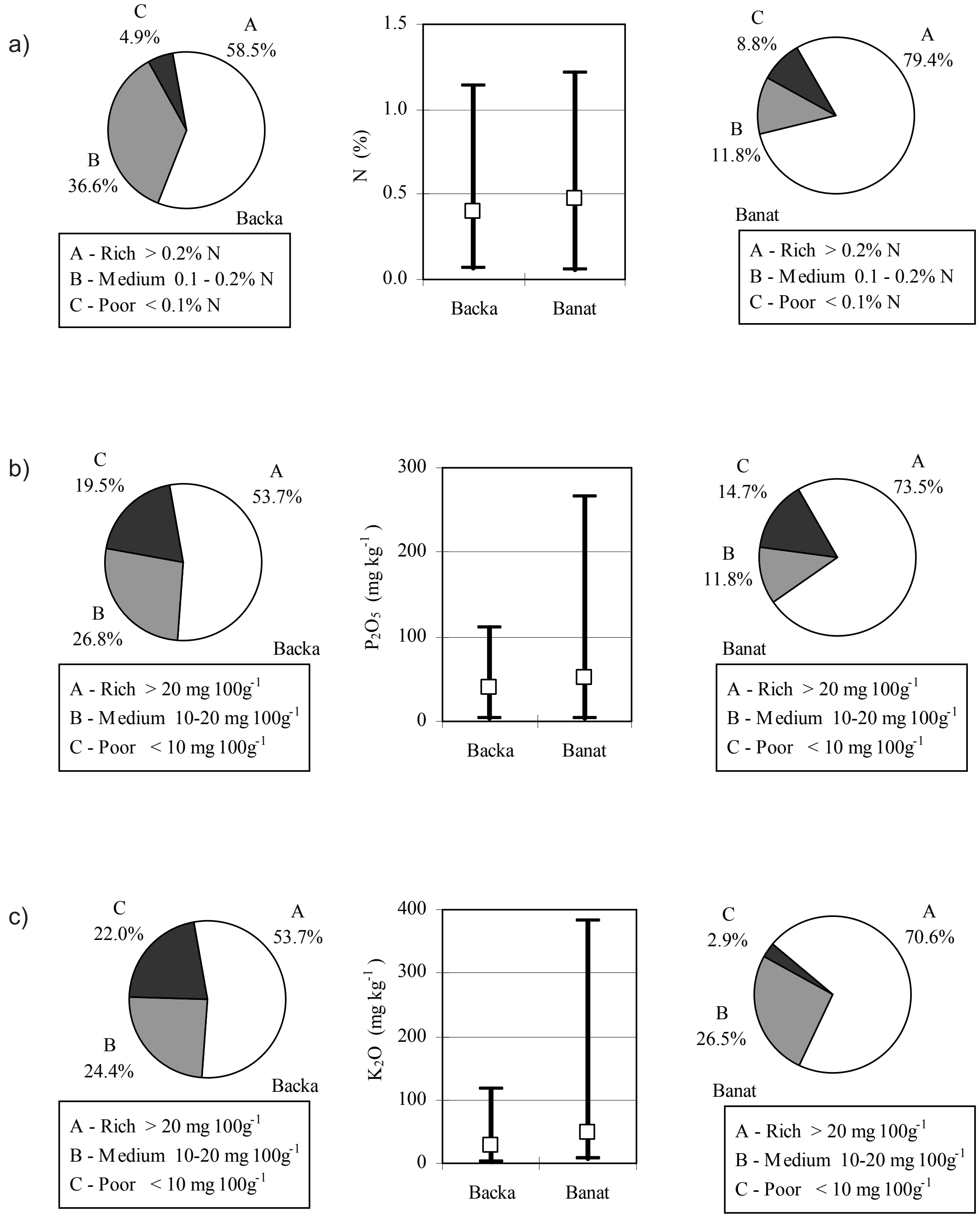

Fig. 2. a) Minimum, maximum, and average concentrations of nitrogen – N (%) in canal sediments from the regions of Backa and Banat. Sediments classification made on the basis of nutrient content.
b) Minimum, maximum, and average concentrations of phosphorus – P_2O_5 (mg 100g^{-1}) in canal sediments from the regions of Backa and Banat. Sediments classification made on the basis of nutrient content.
c) Minimum, maximum and average concentrations of potassium – K_2O (mg 100g^{-1}) in canal sediments from the regions of Backa and Banat. Sediments classification made on the basis of nutrient content.

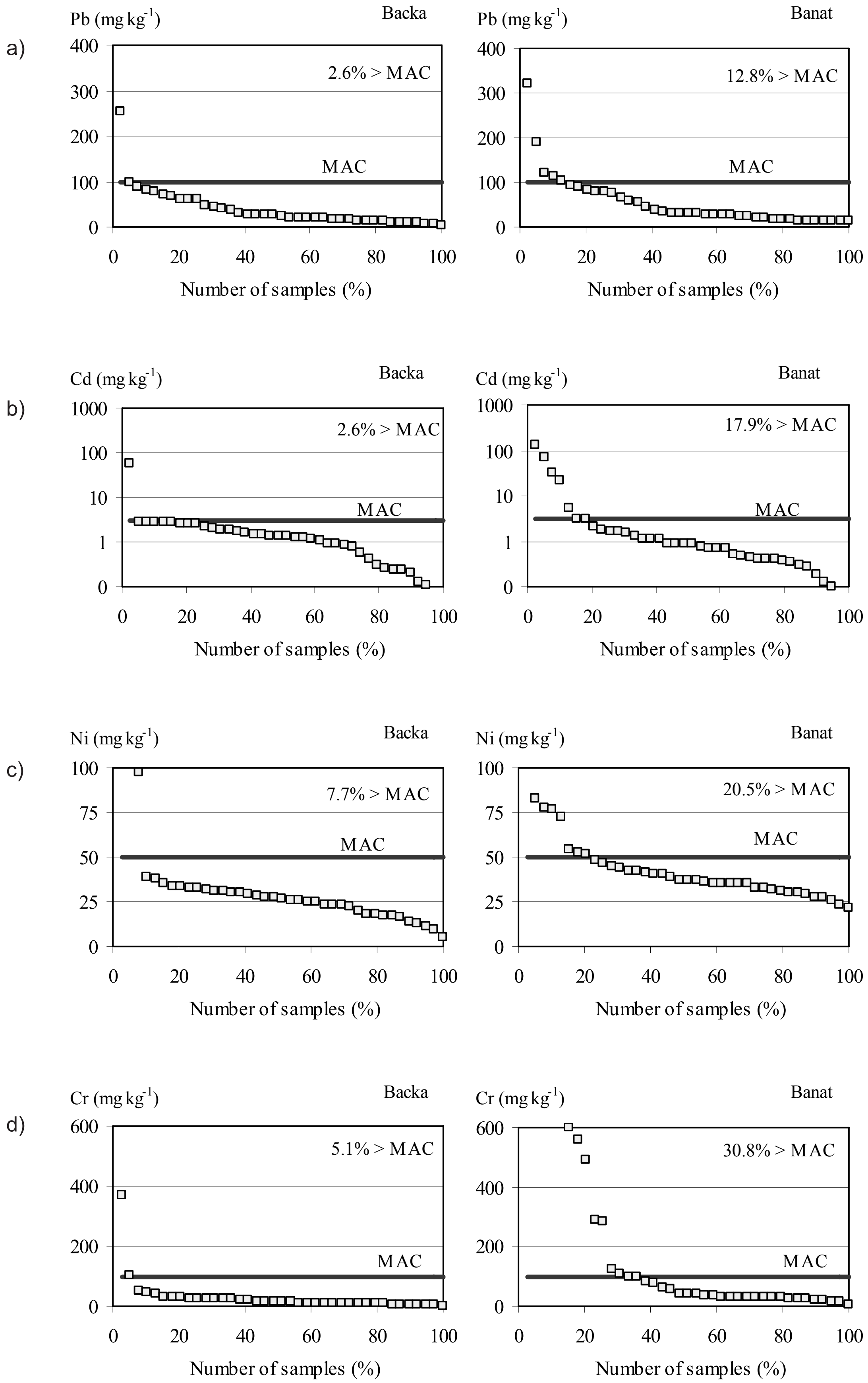

Fig. 3. a) Concentrations of lead (Pb) in canal sediments (mg·kg^{-1} dry weight) from the regions of Backa and Banat in relation to the MAC, 3b. Concentrations of cadmium (Cd) in canal sediments (mg·kg^{-1} dry weight) from the regions of Backa and Banat in relation to the MAC, 3c. Concentrations of nickel (Ni) in canal sediments (mg·kg^{-1} dry weight) from the regions of Backa and Banat in relation to the MAC, 3d. Concentrations of chromium (Cr) in canal sediments (mg·kg^{-1} dry weight) from the regions of Backa and Banat in relation to the MAC.

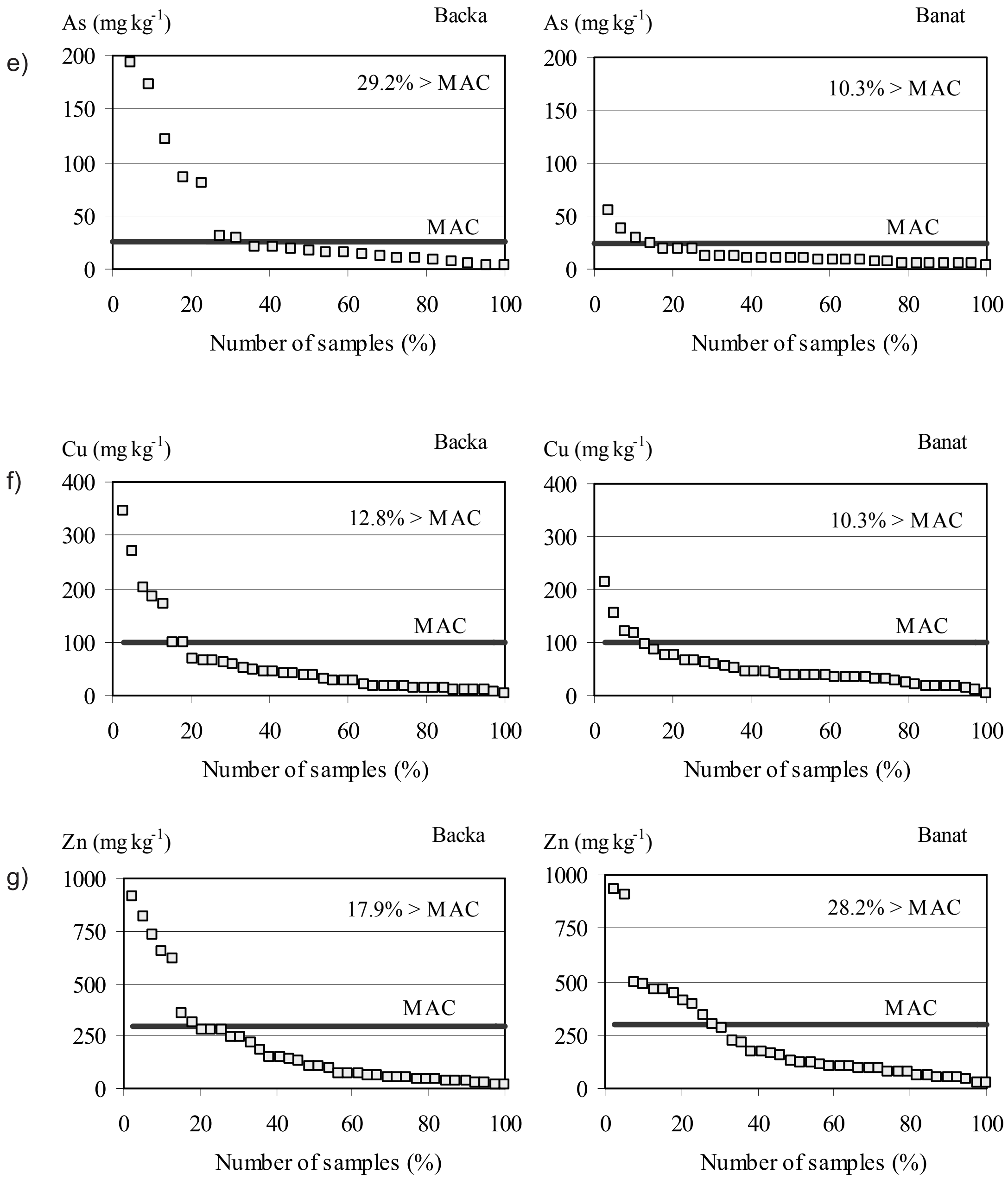

Fig. 3. Continued.
e) Concentrations of arsenic (As) in canal sediments (mg·kg^{-1} dry weight) from the regions of Backa and Banat in relation to the MAC
f) Concentrations of copper (Cu) in canal sediments (mg·kg^{-1} dry weight) from the regions of Backa and Banat in relation to the MAC
g) Concentrations of zinc (Zn) in canal sediments (mg·kg^{-1} dry weight) from the regions of Backa and Banat in relation to the MAC

had lead concentrations above the MAC (100 mg·kg^{-1}). One of these samples had an extreme concentration of lead, 3 times higher than the MAC (the canal near Pancevo – potential polluters are a tannery, and metal and glass industries), Fig. 3a.

Cadmium (Cd)

Cadmium sources are low-quality phosphorus fertilizers, manure, sewage sludge, etc. [29, 30, 32-34]. Most of the sediment samples from Backa had a uniform concentration of cadmium that was below the MAC (3 mg·kg^{-1}). An extremely high value (57.4 mg·kg^{-1}), almost 20 times higher than the MAC, was registered in one sample (the canal near Becej – a slaughterhouse, meat processing industry, a beer brewery). In the samples from Banat, cadmium was often above the MAC (17.9% of the total number of samples). Very high cadmium concentrations (e.g., 134.7 mg·kg^{-1}, 70.5 mg·kg^{-1}, etc.), more than 40 times above the MAC, also were recorded (the canal near Pancevo, mentioned above) Fig. 3b.

Nickel (Ni)

Nickel in the canal sediments typically originated from foundries, sludge from purification plants, fuel and oil com-

Table 2. Characteristic values of heavy metals concentrations in sediments of drainage canals in Backa and Banat.

Parameter	Pb	Cd	Ni	Cr	As	Cu	Zn
Backa							
Min	3.28	0.00	5.11	0.00	3.90	4.79	13.66
Max	253.10	57.40	829.00	367.00	193.20	347.00	910.00
Mean	38.84	2.79	52.09	28.73	40.76	60.32	200.10
SD	42.94	8.91	130.15	57.75	53.90	74.64	230.98
Banat							
Min	12.21	0.00	21.30	7.10	3.40	5.00	22.40
Max	322.32	134.74	101.60	11,540.00	54.76	214.90	932.67
Mean	53.75	7.55	42.72	698.36	13.54	52.33	222.94
SD	58.05	23.99	17.29	2110.41	11.13	41.25	217.10
t-test	-1.27	-1.15	0.44	-1.96*	2.60*	0.58	-0.44

*statistically significant at the $P<0.05$ level

bustion, waste incineration, mineral fertilizers, etc. [29, 30, 35]. Concentrations above the MAC (50 mg·kg^{-1}) were recorded in 7.7% of the samples from Backa. A very high Ni concentration was found in the sediments of one canal, 829 mg·kg^{-1}, or 16.5 times above the MAC (the canal and polluters in the vicinity of Becej). Ni concentrations above the MAC were more frequent in the samples from Banat and amounted for 20.5% of the total samples number (the canals near Pancevo and Zrenjanin, both exposed to several polluters). However, the highest recorded concentration was 101.6 mg·kg^{-1} and exceeded 2 times the MAC limit (Fig. 3c).

Chromium (Cr)

Chromium occurrence in the sediments may be related to the application of phosphorus fertilizers, manufacture of paints and varnishes, sludge or atmospheric conditions [29, 30, 36]. Chromium concentrations above the MAC (100 mg·kg^{-1}) were registered in 5.1% of the sediment samples from Backa. The highest concentration of chromium was 3.6 times above the MAC (the canal near Becej). As many as 30.8% of the sediment samples from Banat had a chromium concentration over the MAC (the canals near Pancevo and Zrenjanin). Several samples had extremely high Cr concentrations, 6,996 mg·kg^{-1} and even 11,540 mg·kg^{-1} (the canal near Pancevo), Fig. 3d.

Arsenic (As)

Certain industries, pesticide residues, detergents, etc. are the main reasons for the possible occurrence of arsenic in canal sediments. Clay and organic matter can easily adsorb arsenic and it can accumulate in surface soil layers, from which it may be transported by soil erosion processes to canals and other water bodies [29, 36-38]. About 29.2% of the sediment samples from Backa had arsenic concentrations above the MAC (25 mg·kg^{-1}). Several samples were found to have high As concentrations, 5 to 7 times above MAC (the canal near Odzaci). Arsenic was found in 10.3% sediment samples from Banat (the canal near Pancevo). The highest concentrations were up to 2 times above the MAC (Fig. 3e).

Copper (Cu)

Copper typically originates from agricultural activities (especially the use of chemicals for grapevine protection), some industrial plants (smelters, etc.), animal farms, and sludge [29-31, 34]. Copper concentrations above the MAC (100 mg·kg^{-1}) were found in 17.9% of the sediment samples from Backa and in 10.3% of the samples from Banat. The highest concentrations were up to 3.5 times above the MAC in Backa (347 mg·kg^{-1} – the canal near Becej; the canal near Vrbas – a pig farm, several food processing facilities; the canal near Backa Topola – waste waters from the urban zone, meat processing industry, an animal feed factory, etc.), and up to 2 times above the MAC in Banat (215 mg·kg^{-1} – the canal near Kikinda – recipient of waste waters from the urban zone, a brickyard, a foundry and metal industry; the canal near Vrsac – waste waters from the urban zone, food processing industry and numerous vineyards), (Fig. 3f).

Zinc (Zn)

Zinc occurs in soil and canal sediments as a result of the application of organic and mineral fertilizers, pesticides, compost, sewage sludge, and it also comes from the atmosphere [29, 30, 34, 35]. Zinc concentrations above the MAC were relatively frequent in the analyzed sediments. Zinc concentrations above the MAC (300 mg·kg^{-1}) were recorded in 17.9% of the samples from Backa (the previously mentioned canals near Odzaci, Backa Topola, Becej, and Vrbas), and 28.2% of the samples from Banat (waste waters from the urban zones and industries near Pancevo, Vrsac and Kikinda). The highest zinc concentration, slightly above 900 mg·kg^{-1} (or about 3 times above than MAC), was found in sediment samples from both regions (the canal near Odzaci in Backa and the canal near Pancevo in Banat) (Fig. 3g).

Table 2 shows the range, average values, and statistical significance of heavy metals concentrations in canal sediments from the regions of Banat and Backa. The average concentrations of Ni, As, and Cu were higher in sediment samples from Backa, while the average concentrations of Pb, Cd, Cr, and Zn were higher in the samples from Banat. In addition, the differences in the concentrations of Cr and As were statistically significant at $P < 0.05$ (Student *t*-test differences in means between the two groups). According to their average concentrations in canal sediments (mg·kg^{-1}) from Backa and Banat, heavy metals were arranged in the following order: Zn> Cu> Ni> As> Pb> Cr> Co> Cd and Cr> Zn> Pb> Cu> Ni> Co> As> Cd, respectively. The differences in the concentrations and distributions of heavy metals in the two regions were due to several factors [39], most important being the number and type of polluters and the intensity of pollution they exerted (untreated waste waters from various industrial facilities and urban areas) and the maintenance of canals (dredging schedule).

Studies of heavy metals in sediments of drainage canals (hydrotechnical facilities for special purposes and with a relatively low water flow) are rare [1, 2, 13, 18]. Studies dealing with sediments in rivers and other natural water bodies are more frequently found in the literature [6-10, 40-43]. Due to specific conditions occuring in the analyzed canals diversified point and nonpoint pollution sources impacted its catchments. The average and especially maximum concentrations of heavy metals reported in this paper are generally on the level or higher than the values given in similar reports [6-10, 40-43].

The presence of heavy metals in canal sediments was typically related with human activities in the catchment area or it was caused directly by polluters. As the canals are subject to a variety of influences, excessive occurrence of certain heavy metals was not uniform. In the samples from Backa, arsenic and zinc were more often above the MACs than the other heavy metals (29.2% and 17.9%, respectively). In the samples from Banat, elevated concentrations of chromium, zinc and nickel were most frequent (30.8%, 28.2% and 20.5%, respectively). Most of the analyzed heavy metals were more frequently found in concentrations above the MAC in the samples from Backa than those from Banat.

Summarizing the presented results, it can be concluded that the sediments from drainage canals in Backa contained heavy metals in concentrations above the MAC in 12 out of 39 (30.8%) analyzed samples. In other words, some of these samples had at least one of these elements, but usually two, three, and up to five, in the concentration over the MACs. In the canal sediments from Banat, excess concentrations of heavy metals were found in 23 out of 39 (59.0%) samples. In some of these samples, the number of elements exceeding the MAC ranged from one to as many as six, but usually it was three or four.

In both analyzed regions, the sediment samples with increased concentrations of heavy metals were typically collected from drainage canals located close to large urban areas where, in addition to drainage water, they also received large amounts of untreated municipal and industrial waste waters. These urban areas are generally away from major rivers or canals and this explains why they discharge effluents into relatively small drainage canals. It was often the case that a number of polluters discharged their waste into a single canal; however, the impact of individual polluters on the concentration of heavy metals in canal sediments was not analyzed in this paper.

This study and its results are important because analyses of the properties of sediments from drainage canals and the impact of canal sediments on the environment are rarely found in the literature. The analyzed drainage canals are important water bodies in Banat and Backa, regions with intensive agriculture. In view of further sustainable development of agriculture and water management in the two regions, these canals, in addition to their principal hydrotechnical and land reclamation functions, also have ambiental and landscape values because they break the monotony of the plain turned into "cultivated steppe." Further, these canals are an important biodiversity factor, providing a habitat and ecological corridor for migration of different plant and animal species [44, 45]. Therefore, the recognition of the ecological significance of the canals, their preservation, development and protection are essential. In that context, it is important to monitor the quality of sediments in the canals in Banat and Backa, because such monitoring can give us an early warning of impending pollution problems, their causes, sources and extent.

Conclusion

Canal sediments are a medium that show a tendency of accumulation and increase in concentration of all substances that become deposited in drainage canals. Taking the major macronutrients (N, P, K) as examples, it was shown that they tended to accumulate in the canal sediments. The contents of these nutrients in the analyzed canal sediments were higher than the corresponding contents found in the arable soil in the studied regions. This phenomenon was more pronounced in the canal sediments from Banat than in those from Backa.

Several samples of sediments from drainage canals were found to contain extremely high concentrations of heavy metals, from a few times to more than 100 times higher than the MAC. In addition, some sediment samples contained excess concentrations of as many as five or six heavy metals. Regarding the concentration of heavy metals, it was concluded that the canal sediments from Banat had higher loads of these elements than the sediments from Backa. Possible causes for this situation are the more intensive erosion processes in Banat and the more extensive use of drainage canals as direct recipients of untreated waste waters than in Backa.

Increased concentrations of nutrients and heavy metals were found in sediments of drainage canals that run near major urban areas and industrial facilities. So, in addition to their main drainage function, these canals became recipients of untreated, highly contaminated municipal and industrial waste waters. These contaminated canal sediments can pose serious environmental problems, impacting not only the canals themselves but also their immediate and wider surroundings.

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