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Nutrients accumulation in drainage channel sediments

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ABSTRACT

The drainage channel network in Vojvodina, northern part of the Republic of Serbia, in total length of around 20,000 km, transfers excessive (under)ground waters from around 2.15 million ha of lowlands. Channels are mostly in direct connection with the surrounding arable agricultural land and are exposed to different run-off, leaching and/or wind erosion processes. Close to urban areas, some channel sections serve as recipients of unrefined sewage and industrial waste waters. Water flows and velocities, as well as the transportable capacity of fluvial materials (sediments) are relatively low. This, in combination with other natural and anthropogenic impacts, contributes to sediment generation in the drainage channel network. Based on around 100 sediment samples from 46 channels, concentrations of primary nutrients (N, P and K) were elaborated in this study. Detected concentrations of macronutrients in the channel sediments (e.g. N 1–1.2%, P 100–265 and K 100–380 mg 100 g^{-1}) exceeded their content in surrounding arable land by a few fold. Also, significantly higher nutrient concentrations (in average by 50%) were detected in downstream (vs. upstream) channel sections. An excessive presence of observed elements in channel sediments, due to interactive processes between water and sediment material, can adversely influence the water quality and life conditions for channel biota and caused other negative environmental impacts such as eutrophication. These results clearly confirm that the processes of nutrient accumulation in channel sediments are greater than those in the surrounding, mostly intensively arable land areas. The erosion of unprotected agricultural areas and sediment transport as the most important pollution pathways from the drainage basin to channel network may be essential factors responsible for detected condition of nutrient accumulation.

1. Introduction

Erosion processes represent one of the most important degradation forms for land and water ecosystems. In spite of the existing opinion that erosion is not a significant and real threat to the predominantly lowland areas of Vojvodina (northern part of Serbia), due to the terrain's configuration and very specific agroecological conditions (e.g. relatively intensive agriculture and agro-hydro-technical systems, medium soil texture), the facts are quite opposite (Savic et al., 2013a, 2013b). Natural and notably anthropogenic influences over this lowland assume that significant areas of arable agricultural land are exposed to interchangeable water and wind erosion processes (Ailincai et al., 2011; Lamba et al., 2015; Li et al., 2004; Riksen et al., 2003). The negative consequences caused by erosion are manifested in direct fertility and/or soil particles loses and in similar *in situ* effects. Another factor is the translocation of sediment particles to certain distances, resulting in temporarily or permanent sedimentation (on the upper layers of estuaries), i.e. *ex situ* effects (Riksen & De Graaff, 2001). Sedimentation processes are especially affected by the relatively dense drainage channel network in Vojvodina, total length around 20,000 km (> 10 m ha^{-1}), which is in direct contact with surrounding intensive arable land areas (Dragovic et al., 2005; Savic et al., 2013a, 2015). Erosion deposited material (sediment) manly originates from agricultural areas, and it is significantly loaded by different in/organic nutrients, pesticides and other harmful and potentially toxic substances. Accordingly, the presence of sediment material in aquatic ecosystems can impair

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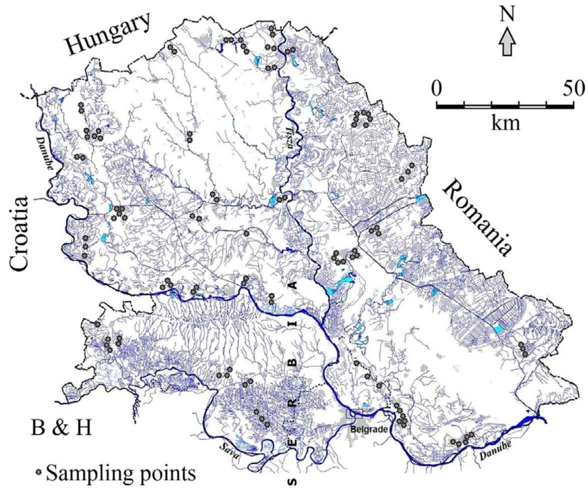

Fig. 1. Map of study area with sediments sampling points.

water and channel sediment quality (Ali et al., 2006; Savic et al., 2015; Schreiber et al., 2005). Also, sediment particles are mostly fractionized to dominant fine clay particles, representing a relatively high reactive surface interface capable for strong adsorption of different soil constitutes (organics, macro/micro elements, different contaminants) (Gerbersdorf et al., 2007; Kisic et al., 2002; Li et al., 2011). This fact certainly contributes that erosion processes being considered as one of the main routs of the transport and spread of diffuse contaminants in drainage basins and surrounding ecosystem(s). Furthermore, adverse impacts of diffuse contamination are not manifested immediately. They have a cumulative impact for a long period, thus complicating analysis of their influence and the possible consequences to environment (Csatho et al., 2007; Sharpley et al., 2009). So, adverse effects of erosion processes can be manifested in different ways, and thus studied from an agronomic, hidrotechnic, economic, social, as well as from an ecological perspective (Savic et al., 2015).

In this paper, the sediment quality in the drainage channel network of Vojvodina was presented in respect to certain physical (particle size distribution) and chemical (N, P, K) properties. An excessive presence of elaborated nutrient elements in the channel sediments, due to interactive processes between the water medium and the sediment material can adversely influence water quality and life conditions for channel biota, not only *in situ* but also in terms of other recipients, e.g. secondary/primary channels, streams, rivers, lakes etc. (Chambers et al., 2000; McDowell & Sharpley, 2009; Neal et al., 2008). Finally, this presence may accelerate eutrophication processes and other related negative environmental pressures (Istvanovics & Honti, 2012).

2. Material and methods

2.1. Study area

In the study period, from 2004 to 2012, a sampling of sediments at 46 ameliorative (drainage) channel locations overall of Vojvodina, northern part of the Republic of Serbia (N 46°11'-44°37'; E 18°51'-21°34') was conducted, covering in total 2.15 million ha. More than 75% of elaborated territory was overspread on intensively arable agricultural land areas (Dragovic et al., 2005), while some of channel sections were spread very close to urban and industrial zones (Fig. 1), serving as recipients for different under/ground effluents such as unrefined sewage and/or industrial waste water. The observed channel network characterizes relatively low hydraulic properties with an average depth of 1–1.5 m and water flow mostly up to 1 $m^3 s^{-1}$ (Savic et al., 2013a, 2015).

2.2. Sampling and analysis

At each of 46 drainage channel locations, at least two sediment samples (the first at upstream and the second at downstream channel profile section) were collected, generating in total 100 samples (Fig. 1). All samples of sediment materials were collected in a disturbed state, from the bottom of the drainage channel (0–20 cm) by a special sediment probe, stored adequately and prepared for physico-chemical analyses in the accredited soil laboratory (International Organization for Standardization ISO, 2005) at the Institute for Field and Vegetable Crops (Novi Sad, Serbia). In short, the particle size distribution (sediment texture) and concentration of macronutrients; nitrogen (N), physiological active phosphorous (P_2O_5) and potassium (K_2O) were determined according to standard procedures and methods. Based on detected concentrations of analysed nutrients, channel sediments were classified according to commonly accepted agronomic criteria as rich, medium or poor (Bogdanovic et al., 1993; Zivkovic et al., 1972), and after that compared to nutrient levels for the Chernozem soil type (International Union of Soil Science Working Group World Reference Base IUSS WRB, 2015) as one of the most productive and dominant land resource of surrounding agroecosystems (e.g. Dragovic et al., 2005; Savic et al., 2015). Summary statistics of the dataset was calculated to evaluate the distributions and frequency for each analysed parameter (based on histograms calculation of skewness and kurtosis), whereas correlation matrix between observed elements was estimated by Pearson's correlation coefficient. All data were statistically processed and calculated using the Statistica 8 software package.

3. Results and discussion

Summary statistics for the particle size distribution in channel sediments is presented in Table 1. It was detected that in observed channel sediments the most dominant fraction was the fraction of fine sand, ranging from 12 to 88% (in average 43%), following silt (in average 23%), then course sand (in average 20%) and finally clay particles (in average 15%), (Fig. 2). Also, coefficients of variation for the particle size distribution in sediments material confirmed pronounced inhomogeneity (CV > 30%), (Table 1). Such interrelation in particle size distribution is very common patterns of erosion processes, i.e. for transport and sedimentation of erodible material in ameliorative channel network, given that particles of detected distribution are the most susceptible for fluvo-translocation/deposition (Liu et al., 2015; Rienzi et al., 2013).

The deposition of erosion material in water bodies of drainage channel network causes sediment congestion at first, i.e. mechanical constrain. However, due to significant presence and influence of diffuse contamination, an excessive concentration of nutrients and potentially toxic materials (i.e. chemical constrain) is also possible in such environments. Negative consequences of such cumulative processes can particularly be observed within the interactive processes of water medium and sediment material (Brils, 2008; Fataei & Nasehi, 2012; Forstner & Salomons, 2008; Morse et al., 2004). This can adversely compromise the quality and availability of hydrological resources, as well as the overall condition of all other environmental resources.

The primary sources of nutrients in most of intensive agroecosystems are mineral and/or organic fertilizers. Overuse and/or mismanagement of these products may have impacts on the quality of soil/water resources as well as on safety of food crops. For instance, one of unfavorable influences of nonsustainable management by nutrients in agriculture can be manifested through an intensification of eutrophication processes, accompanied by all another detrimental impacts for steady channel water flows/velocities (Dodds & Welch, 2000; Istvanovics & Honti, 2012). In general, the total consumption of fertilizers in European countries has stabilized in recent 6-year period (e.g. nitrogen 10.1–11.1; potassium 2–2.4 and phosphorous 1–1.1 million tons per year), following a significant decline during the 1990s (European Environment Agency (EEA), 2004; Eurostat, 2016). These reduction (stabilization) is mostly the result of implementation of EU legislation, principally the Nitrates Directive, which helps to limit nutrient losses from agricultural farms to freshwater bodies by restricting nutrient use in designated nitrate vulnerable zones (European Council, 1991). Namely, some of the most important nutrient elements, with regard to their concentration and harmful effects for the environment, are nitrogen (N) and phosphorous (P), followed by potassium (K) and other micronutrient elements (Smal et al., 2013). Nitrogen is generally known as a dominantly diffuse contaminant from agriculture. In its nitrate form, N is very soluble and mobile and thus relatively easily can be leached from the topsoil to subsoil horizons and/or hydro resources. The main cause of excessive N concentrations in some natural resources is imbalance in agricultural crop nutrition and fertilization. In spite of a tendency for reduction in the application of fertilizers, P and N content and their loads are continuously increasing in natural resources of some regions (e.g. with intensive livestock production, dry and warm Mediterranean agroecosystems with low removal rates by harvested crops) of the European Union (EEA, 2004). Land imbalances of P, especially in the topsoils, are one of the running factors for P deposition in river estuaries (Correll, 1998; Farkas et al., 2013; Haygarth & Jarvis, 1999; Haygarth et al., 2013). Namely, the main portion ($>70\%$) of P in such alluvial areas is present in dissolved, colloidal or electro-statically bounded sediment particles and originates from arable land areas (Csatho et al., 2007).

Table 1
Basic statistics on particle size distribution of sediments sampled in drainage channels.

	A Coarse sand	B Fine sand	C Silt	D Clay
Size (mm)	> 0.2	0.02–0.2	0.02-0.002	< 0.002
Min.	0.90	12	0.0	2.0
Max.	65	88	47	50
Avg.	20	43	23	15
St. dev.	15	18	10	11
Skew.	0.3	0.0	0.1	1.3
Kurt.	0.9	0.8	-0.3	1.3
CV (%)	75	42	44	72

The content of analysed macronutrients in channel sediments was detected in a wide range, as might be expected in view of the diversity of the sediments regarding to processes of their formation, their origin and natural/anthropogenic influences to which they were exposed (Sharpley et al., 2009; Spooner et al., 2013). For example, N content varied from a minimum of 0.03% to a maximum of 1.22% with an average content of 0.409%. The concentration of physiologically active phosphorous (P_2O_5) oscillated from 4.3 to 266 mg 100 g^{-1} (on average 45 mg 100 g^{-1}), whereas the concentration of physiologically active potassium (K_2O) ranged from 3.5 to even up to 382 mg 100 g^{-1} (on average 38 mg 100 g^{-1}). Also, distribution of analysed nutrients in channel sediments was shown to be asymmetric (skewness ≥ 1; kurtosis > 0), especially in the case of P_2O_5 and K_2O, (Table 2). These results suggest on very possible influence of some other anthropogenic sources on sediments quality, such as direct release of unrefined effluents from urban and/or industrial zones. Also, the detected values of nutrients in most sediment samples (Table 2) significantly exceeded their average content in surrounding intensively arable land area, such as dominantly present Chernozem soil type (i.e. 0.17% N, 21 and 23 mg 100 g^{-1} P_2O_5 and K_2O respectively), (Bogdanovic et al., 1993; IUSS WRB, 2015; Zivkovic et al., 1972). For instance, it was detected that in around of 83% of analysed channel sediment samples N content exceeded the average reference N content for Chernozem soil type by >7.5-fold (in average by 2.4-fold) (Fig. 3). In $>60\%$ of analyzed sediment samples P and K content exceeded their average reference level for surrounding dominant Chernozem soil type. Also, it was detected that P and K content in channel sediments exceeded those in surrounding land by 12.5-fold and 17-fold respectively (in average by 2-fold), (Fig. 3).

According to commonly accepted agronomic criteria for nutrient content in lands (Bogdanovic et al., 1993; Zivkovic et al., 1972), the most dominant portions of analysed samples appertain to rich (A) and medium (B) classes (Fig. 3). In respect to N content, 71% of the samples were rich, and 20% were medium enriched in N content, i.e. 91% of the samples appertained to A and B classes. In the case of P, 64% of samples were rich and 22% were medium

Table 2
Basic statistics on analysed nutrients in sediments sampled in drainage channels.

Parameters	N (%)	P_2O_5 (mg 100 g^{-1})	K_2O (mg 100 g^{-1})
Min.	0.03	4.3	3.5
Max.	1.22	266	382
Avg.	0.41	45	38
St. dev.	0.30	44	46
Skew.	1.00	2.55	4.9
Kurt.	0.12	9.1	32
CV (%)	73	98	123

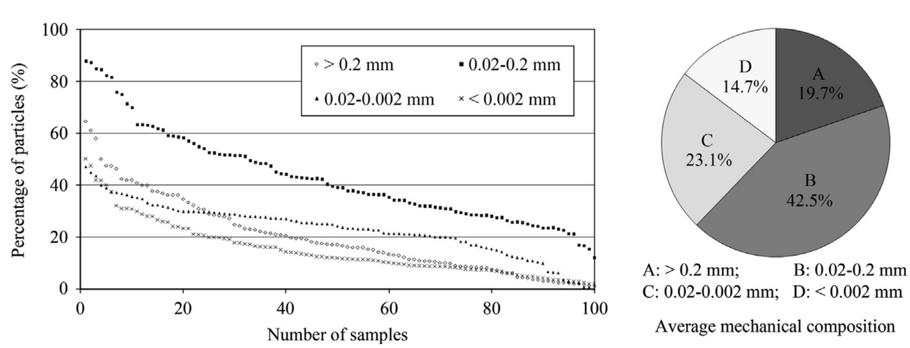

Fig. 2. Particle size distribution of sediments sampled in drainage channels.

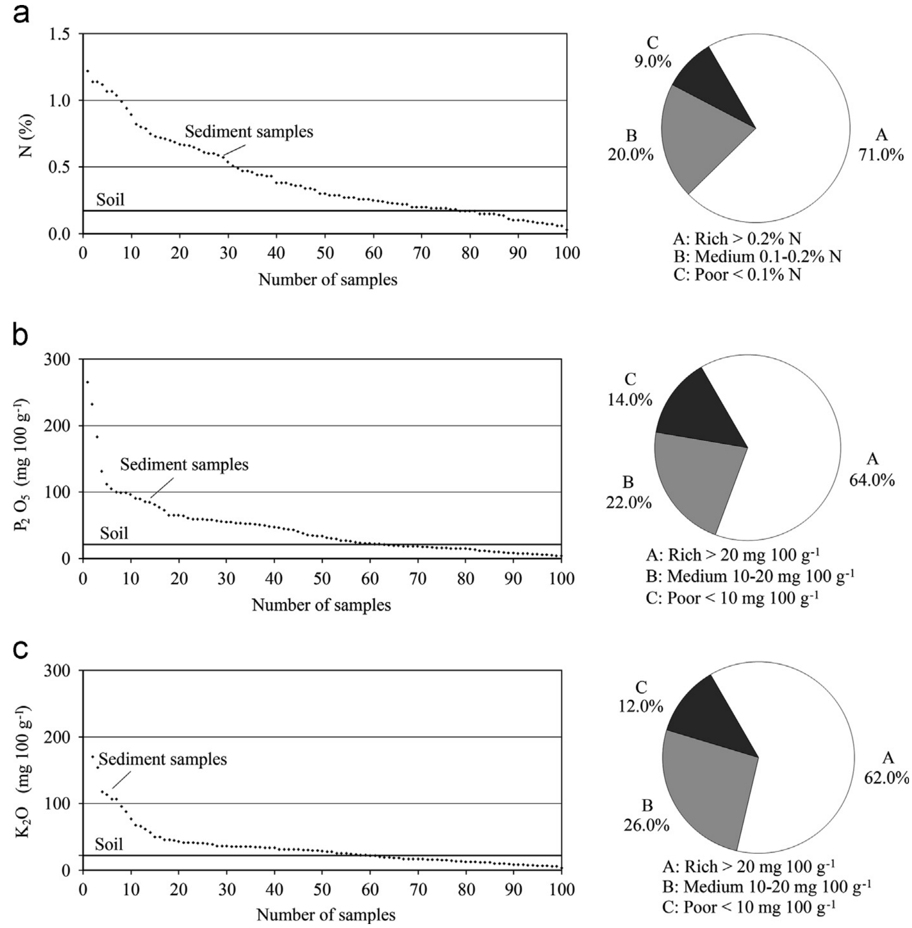

Fig. 3. Left part – nutrients content in observed channel sediments in relation to average nutrient content for the Chernozem soil type (Soil). Right part – channel sediments classification given on nutrient levels according to commonly accepted agronomic criteria (e.g. Bogdanovic et al., 1993; Zivkovic et al., 1972).

enriched by P (in total, 86% of the samples consisted of A and B classes). A similar distribution of drainage channel sediment samples was detected for K, where 62% of samples were rich and 26% were medium enriched by K, i.e. 88% of samples appertained to A and B classes (Fig. 3). Moreover, in some channel sediment samples, uncommonly high nutrient concentrations in comparison to their average content in surrounding arable soils/sediments were also detected. For instance, N content in around 10% of observed samples was relatively high 1–1.2%, P_2O_5 concentration in certain samples was >100, with maximum of 265 mg 100 g^{-1}, as well as K_2O concentration in around 8% of the samples was in the range of 100–380 mg 100 g^{-1}.

Because the occurrence of the channel sediments is mostly the result of erosion processes, it can be concluded that the role of erosion in diffuse contaminant transport from the surrounding arable agricultural land to the drainage channel network is of critical importance. However, it must be highlighted that the very high concentration of some nutrients in the analysed sediment material may originate not only from diffuse contaminant (agricultural fertilisers) but also from point (concentrated) contaminant sources such as direct release of unrefined sewage and industrial and/or animal farm waste water (Savic et al., 2015). That was actually confirmed in the most nutrient-enriched samples, taken at the network sections running near large urban areas which directly receiving untreated municipal and industrial waste waters. These canal sections were in most cases very likely exposed to combined effects of several different pollution sources but their individual contributions were not considered in this paper.

Concentrations of nutrients in analyzed regions of Vojvodina are in direct relations to hydrological and hydrotechnical conditions of the catchment area at first, however they also depend on land and water use and management practices (e.g. irrigation, fertilization, sediment dredging) (Farkas et al., 2013; Palmer-Felgate et al., 2009). It is also important to take into account the location of urban areas and industrial facilities, as well as their proximity to rivers and main canal network which can be more available recipients of waste waters than drainage canals (Fig. 1).

Increased concentrations of observed macronutrients were confirmed in downstream channel sections also. Namely, the highest nutrient concentrations were detected in samples taken from downstream locations, as compared to those taken from upstream channel locations what clearly indicates on cumulative processes of nutrient deposition. The influence of combined diffuse and/or point source contamination between up/downstream locations resulted in increased nutrient content at downstream samples in average up to 50% for N and between 30–40% for P and K, (Fig. 4).

Furthermore, at some downstream locations, the concentrations of all analysed macronutrients were >5-fold higher compared to those at upstream locations. For instance, the difference in the K concentration between particular up/downstream locations was the most varied, by 5.4 times (e.g. 20 mg 100 g^{-1} at upstream and 107 mg 100 g^{-1} at downstream section), whereas the P concentration in the same relation was the least varied, by 4.9 times (e.g. 10.9 mg 100 g^{-1} at upstream and 53 mg 100 g^{-1} at downstream section). Similarly for P, there was a confirmed

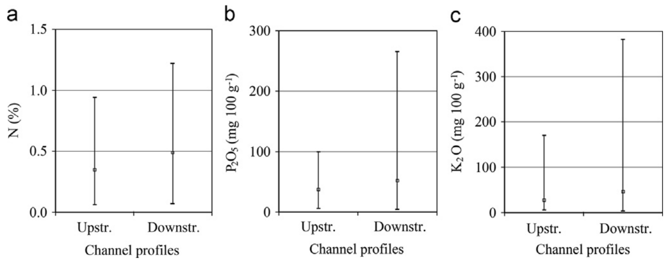

Fig. 4. Range of nutrient concentrations in sediments sampled at upstream (Upstr.) and downstream (Downstr.) drainage channel profiles (locations).

Table 3
Correlation matrix of particle size distribution and nutrients in sediments sampled in drainage channels.

Nutrients	Particle size (mm)			
	> 0.2	0.02–0.2	0.02-0.002	< 0.002
N (%)	+0.62*	-0.53*	+0.03	+0.18
P_2O_5 (mg 100 g^{-1})	+0.51*	-0.30	-0.07	+0.01
K_2O (mg 100 g^{-1})	+0.28	-0.27	0.00	+0.01

* significant at the $p < 0.05$.

difference in N content (5-fold) between certain upstream (0.15%) and downstream (0.75%) channel locations (Fig. 4).

Some previous studies based on well-structured and resilient recourses regarding to Chernozem have confirmed certain water and wind erosion processes that do not exceeded the dimensions of natural geological erosion. However, due to size of investigated area and detected concentrations and chemical properties of analysed nutrients, as well as sedimentation of materials, erosion must be recognised as very serious degradation process in terms of natural resources of Vojvodina (Savic et al., 2013b).

Obtained correlations coefficients are presented in Table 3. For instance, moderate positive correlation was detected among particles with size >2 mm and N (r=+0.62) and P_2O_5 (r=+0.51) concentration, whereas negative correlation was detected among particles with size 0.02–0.2 mm and N (r=-0.53) and P_2O_5 (r=-0.30). There was no detected correlation (r was in the range 0–0.18) among nutrients and the finest (silt and clay) channel sediment fractions (Table 3). Influence of the particle size distribution in channel sediments was correlated with analysed nutrients as was applied in some similar studies (Hossain & Hossain Bhuiyan, 2015; Noah et al., 2007).

4. Conclusions

Channel network sediments usually represent a very suitable medium for the accumulation of different in/organic materials that reach the drainage network. In this study, based on the example of the most important macronutrients (N, P, K), their accumulation in channel sediments was clearly confirmed. The macronutrient content of all observed nutrients in the channel sediments was significantly higher (N by 1-fold, P and K by 2-fold) than in surrounding arable Chernozem soils. Also, in average by 50% increased content (accumulation) of analysed nutrients has been conformed along particular channel sections, i.e. significantly higher nutrient content was detected at downstream than at upstream channel sections. Contamination transport in erosion processes represents only one segment in the investigation and elucidation of a very complex problem (i.e. diffuse-source contaminants), and is still not treated adequately and seriously recognised in the protection of environmental resources on elaborated area.

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