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PHOSPHORUS IN BOTTOM SEDIMENTS OF RIVERS FROM WITHIN THE UPPER NAREW CATCHMENT

FOSFOR W OSADACH DENNYCH RZEK Z OBSZARU ZLEWNI GÓRNEJ NARWI

Abstract: The aim of present study was to determine the content of phosphorus in bottom sediments from rivers of the Upper Narew catchment area. The study deals with tracing the changes of phosphorus in bottom sediments on the background of the spatial distribution of point sources of this nutrient, and identifying the main factors of its enrichment related to morphometry and management of catchment. The study was focused on the Narew River in 10 measurement sections within the stretch Bondary – Tykocin and the Supraśl River, on which six measurement points were selected. During the selection of the bottom sediment sampling sites, the presence of sites where the aquatic environment is improved in phosphorus (mainly sewage treatment plants), was adopted as the main criterion. Samples for analyses were also collected from 17 smaller and larger tributaries of Narew River. The highest contents of phosphorus in bottom sediments were found in Narew River (1.31 gP · kg^{-1} d.m.), while the lowest in river Strabelka (0.10 gP · kg^{-1} d.m.). Comparison with other research revealed that studied sediments were characterized by a typical content of phosphorus, and locally increased amounts of this element are the result of limited, however still existing anthropogenic pressure. The results indicate a relationship between phosphorus in bottom sediments and the nature of particular rivers catchments, including the amount of sewage discharged into these rivers.

Keywords: phosphorus, bottom sediments, rivers, sewage

Introduction

Phosphorus in bottom sediments is a subject of research for its role in the eutrophication of surface waters. The sediments can raise the load of phosphorus to the super-sediment water at a level comparable to an external source [1].

Studies of phosphorus in bottom sediments are a key factor for understanding the cycle of the element in rivers and lakes. This is also essential in the management and reclamation projects related to water reservoirs and rivers [2].

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It should be emphasized the importance of this research in the context of pollution of the Baltic Sea by phosphorus compounds. The total load of the Baltic Sea by the phosphorus from Polish sources constituting 37 % of the overall pollution is transported from the waters of the rivers [3]. These inputs include inputs from natural background sources as well as anthropogenic sources.

Bottom sediments are an important link in the river bed. They have a buffering property; they may bind certain minerals and elements from waters and transfer them to waters. The chemical composition of bottom sediments, including the amount of phosphorus, is affected by natural and anthropogenic factors such as geological and geomorphological structure, climatic conditions (critical for rock weathering, mobilization, migration, and accumulation of elements within the environment), as well as the degree of urbanization and industrialization of a given area [4].

Phosphorus inputs to rivers are traditionally classified as either point or diffuse, although there is some overlap between these classifications [5].

The aim of present study was to determine the content of phosphorus in bottom sediments from rivers of the Upper Narew catchment area. The study deals with tracing the changes of phosphorus in bottom sediments on the background of the spatial distribution of point sources of this nutrient, and identifying the main factors of its enrichment related to morphometry and management of catchment.

Material and methods

The study was focused on the Narew River in 10 measurement sections within the stretch Bondary – Tykocin (Fig. 1) and the Supraśl River, on which six measurement points were selected.

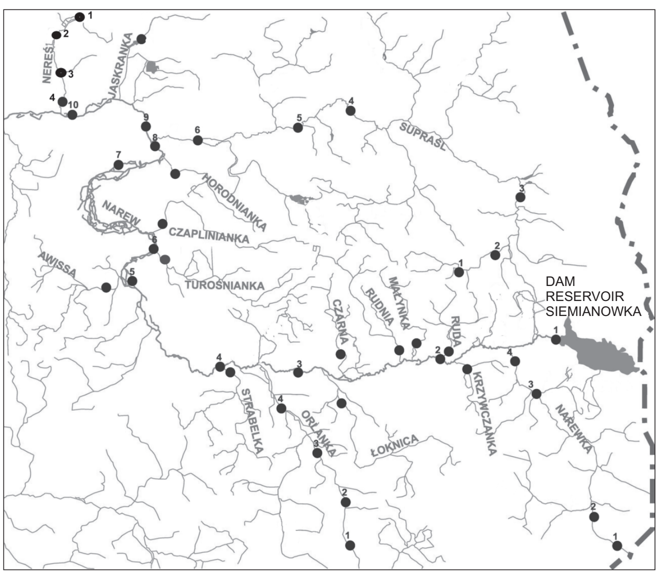

Fig. 1. Localization of bottom sediments sampling points within upper Narew River catchment

During the selection of the bottom sediment sampling sites, the presence of sites (mainly sewage treatment plants), where the aquatic environment is enriched in phosphorus, was adopted as the main criterion. Samples for analyses were also collected from 17 smaller and larger tributaries of Narew River (Fig. 1). Table 1 presents characteristics of studied rivers and their catchments.

Table 1

Characteristics of studied rivers and their catchments [8]

River	Structure of catchment area				Length of rivers	Catchment area	Amount of domestic sewage discharged to rivers
	Urbanized areas	Arable lands	Meadows and pastures	Forests			
	[%]				[km]	[km^2]	[$m^3 \cdot d^{-1}$]
Narew	6	40	20	25	199	6270	444
Suprasl	3	39	28	30	94	1800	650
Narewka	3	15	12	70	48	680	385
Orlanka	6	37	53	4	53	521	70
Neresl	10	59	21	10	39	291	3120
Jaskranka	8	33	41	15	22	120	263
Czarna	4	47	29	20	16	45	—
Ruda	4	43	23	30	12	60	—
Rudnia	4	47	20	22	23	90	—
Czaplinianka	5	43	28	18	17	80	—
Łoknica	3	59	23	15	28	183	—
Awissa	8	54	19	14	15	130	3738
Mienka	3	60	26	11	7	60	—
Turosnianka	5	53	30	12	22	144	—
Horodnianka	15	40	26	18	18	76	900
Krzywczanka	4	52	24	20	10	25	—
Malynka	3	63	14	20	15	60	—
Strabelka	3	45	30	21	16	33	—

Number of selected measurement points on these rivers depended on the catchment area and the river length, and was usually reduced to two, three or four (springs, points in the middle section of the river, estuary). The study was conducted once in 2007. Several individual (7–10) samples of the surface layers of bottom sediments (0–10 cm) in the coastal zone were collected from every selected control-measurement point. The coastal zone is characterized by the deposition of suspended material [6]. After mixing, the test material composed a representative sample.

Samples were transferred to the cuvettes and allowed to completely dry. Air-dry material was ground in an agate mill, dried at a temperature of 105 ^{o}C to constant weight and particular aliquots of samples were prepared for determination. The particulate samples were sieved through a sieve with a mesh of 0.2 mm. This is the type of deposit fractionation commonly used in the geochemical mapping works [7].

Fractions of less than 0.2 mm grain size were used for further study. Sediment samples mineralized in a mixture of sulfuric acid and hydrogen peroxide in acid reflux. After mineralization in the solutions phosphorus were examined by colorimetric method with ammonium molybdate and ascorbic acid.

A total of 41 results of phosphorus content were achieved (Table 2). Arithmetic mean values and standard deviation (SD) of the results referring to sediments from rivers Narew, Supraśl, Narewka, Orlanka and Neresl were calculated. The relationships between results were determined by calculating the Spearman correlation coefficient "*r*" (nonparametric test).

Results and discussion

Phosphorus contents in studied bottom sediments ranged from 0.10 $g \cdot kg^{-1}$ to 3.90 $g \cdot kg^{-1}$ d.m. (Table 2), while arithmetic mean of these contents was 0.57 $g \cdot kg^{-1}$ d.m. [9].

The concentrations of total phosphorus in sediment of Xiangxi River in China ranged from 0.76 to 1.44 $g \cdot kg^{-1}$. The Xiangxi River is 469.7 km long, with a watershed area of 3,099.4 km^2 [9].

Results showed that the content of total P in the sediments in Daliao River, China, ranged from 0.23 to 0.84 $g \cdot kg^{-1}$, with an average of 0.55 $g \cdot kg^{-1}$. The Daliao River system consists of the Daliao River, Hun River and Taizi River, with 94, 415 and 413 km in length, draining 1390, 11,500 and 13,900 km^2 of land area, respectively [10].

The total P in the sediments in Han River, Seoul, Korea, ranged from 0.58–1.15 $g \cdot kg^{-1}$. The Han River, the largest river in Korea, is the primary water source for more than 20 million people in Seoul and the surrounding area. It starts in north-east Kangwon-Do and flows to the Yellow Sea through Seoul. The river is 469.7 km long [11].

The Swale River in UK drains a rural catchment with no major urban and industrial areas, and the total phosphorus content of fluvial sediment is generally within the range 0.50–1.50 $g \cdot kg^{-1}$. Swale River (1363 km^2) drains a largely rural (moorland and agricultural) area. This river is a relatively unpolluted one along its entire length, and drains a predominantly rural catchment with a low population density [12].

Analysis of the main sources of phosphorus within the catchment of upper Narew River revealed hypothesized may be the sewage discharges – mostly domestic and farm (Table 1) – from small towns, cities and above all from Bialystok city (industrial wastewaters in part) localized within the catchment. The sewage treatment plants operate in these places, but periodically they are not able to remove sufficient amounts of phosphorus and other redundant components from wastewaters.

Studies revealed following average contents of phosphorus in the bottom sediments of Narew River – 1.31 $g \cdot kg^{-1}$ d.m., Supraśl – 0.33 $g \cdot kg^{-1}$ d.m., Narewka – 0.40 $g \cdot kg^{-1}$ d.m., Orlanka – 0.24 $g \cdot kg^{-1}$ d.m., and Nereśl – 0.36 $g \cdot kg^{-1}$ d.m. In each of these cases, the influences of point sources of phosphorus forms, mostly related to

Table 2

Phosphorus content in bottom sediments of rivers within upper Narew River catchment

River	Localization of measurement point	[g · kg^{-1}]
Narew	1. Bondary	0.40
	2. Narew	0.70
	3. Ploski	3.50
	4. Doktorce	0.85
	5. Uhowo	0.20
	6. Bokiny	0.20
	7. Rzedziany	0.55
	8. Zlotoria	1.10
	9. Siekierki	1.65
	10. Tykocin	3.90
	Arithmetic mean	1.31
	SD	1.34
Suprasl	1. Topolany	0.30
	2. Michalowo	0.30
	3. Grodek	0.25
	4. Suprasl	0.35
	5. Nowodworce	0.25
	6. Fasty	0.55
	Arithmetic mean	0.33
	SD	0.11
Narewka	1. Bialowieza	0.30
	2. Narewka	0.75
	3. Lewkowo	0.30
	4. Eliaszuki	0.25
	Arithmetic mean	0.40
	SD	0,24
Orlanka	1. Orla	0.25
	2. Krzywa	0.25
	3. Kotly	0.25
	4. Chraboly	0.20
	Arithmetic mean	0.24
	SD	0.03
Neresl	1. Czechowizna	0.25
	2. Bajki Zalesie	0.55
	3. Piaski	0.20
	4. Fasty	0.45
	Arithmetic mean	0.36
	SD	0.17

Table 2 contd.

River	[g · kg^{-1}]
Jaskranka	0.20
Czarna	0.50
Ruda	0.75
Rudnia	0.40
Czaplinianka	0.30
Loknica	0.20
Awissa	0.40
Mienka	0.25
Turosnianka	0.50
Horodnianka	0.25
Krzywczanka	0.20
Malynka	0.40
Strabelka	0.10

sewage treatment plants functioning within the catchment area, can be found. Spatial distribution of phosphorus contents in bottom sediments of Narew River (points 1, 2 and 3) (Fig. 1, Table 1) can also indicate the impact of the water reservoir Siemianówka. In the summer, during an intense algal bloom, the reservoir becomes a major source of phosphorus to the waters of Narew River.

The impact of Biała River that transports contaminants from the city of Bialystok to Supraśl River is also prominent (point 6 – Fasty 0.55 g · kg^{-1} d.m.) (Fig. 1, Table 2). The effect of Bialowieza and Narewka River (municipal waste treatment plants) on the amount of phosphorus in bottom sediments of Narewka River can be also noted (point 2, 0.75 g · kg^{-1} d.m.). Considering the group of small rivers, the largest concentrations of phosphorus were recorded in sediments of Ruda River (0.75 g · kg^{-1} d.m.), while the lowest levels of this element – in bottom sediments of Strabelka River (0.10 g · kg^{-1} d.m.). The Geochemical Atlas of Poland [13] provides details of the descriptive statistics for the group of 993 analyzed sediment samples collected from different lakes. The phosphorus content in these samples ranged from < 0.05 g · kg^{-1} to 8.01 g · kg^{-1} d.m., and the arithmetic mean value amounted to 0.28 g · kg^{-1} d.m. It can be concluded that the quantity of phosphorus in bottom sediments of the upper Narew River catchment is not large, but slightly increased probably due to anthropogenic pressure.

The studies and calculations show that the greatest impact on the amount of phosphorus in the bottom sediments was exerted by: urbanized areas and the volume of sewage ($r_{0.05}$ = 0.45 and $r_{0.05}$ = 0.40, respectively) (Table 3). Urbanized areas, length of river and catchment area shape the volume of sewage discharged into the rivers, which was expressed by means of Spearman coefficients $r_{0.05}$ = 0,57, $r_{0.05}$ = 0.48, $r_{0.05}$ = 0.61, respectively. In part, that confirmed the dependence of phosphorus concentrations on the percentage of urbanized areas surface in the upper Narew River catchment. Forests localized within the catchment area have little influence on the quantities of phosphorus in bottom sediments of upper Narew River catchment ($r_{0.05}$ = 0.20).

Table 3

Spearman correlation coefficients (r) for achieved dependencies ($p < 0.05$)

Component	Urbanized areas [%]	Forests [%]	Length of river [km]	Catchment area [km^2]	Amount of domestic sewage discharged into the rivers [$m^3 \cdot d^{-1}$]
Phosphorus in bottom sediments [%]	0.45	0.20	n.s.*	0.25	0.40
Amount of domestic sewage discharged into the rivers [$m^3 \cdot d^{-1}$]	0.57	n.s.	0.48	0.61	—

* n.s. – not significant.

The studies phosphorus in bottom sediments of rivers are conducted less frequently in comparison with deposits in lakes, thus a smaller amount of scientific publications dealing with the phosphorus in river sediments. However, studies of phosphorus in bottom sediments of rivers should be carried out more frequently due to the large number of point sources of this nutrient, usually in the form of sewage treatment plants. Bottom sediments of rivers can become, under certain conditions, a secondary source of phosphorus to the river waters, like point and surface sources.

Conclusions

1. The highest contents of phosphorus in bottom sediments were found in Narew River (1.31 $g \cdot kg^{-1}$ d.m.), while the lowest in Strabelka River (0.10 $g \cdot kg^{-1}$ d.m.).

2. Comparison with other research revealed that studied sediments were characterized by a typical content of phosphorus, and locally increased amounts of this element are the result of limited, however still existing anthropogenic pressure.

3. The study demonstrates a relationship between phosphorus in bottom sediments and the nature of particular rivers catchments, including the amount of sewage discharged into these rivers.

4. Method of management and morphology of the catchment determine the quantitative migration of phosphorus into the surface waters and then to the bottom sediments. These sediments may contribute to additional, secondary enrichment of waters with phosphorus, which should be one of the pretexts for the continuous quantitative monitoring of the element in the bottom sediments of rivers.

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FOSFOR W OSADACH DENNYCH RZEK Z OBSZARU ZLEWNI GÓRNEJ NARWI

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Abstrakt: Celem pracy było określenie zawartości fosforu w osadach dennych rzek z obszaru zlewni górnej Narwi. W pracy analizowano zmiany zawartości fosforu w osadach na tle przestrzennego rozkładu punktowych źródeł tego składnika oraz zidentyfikowano główne czynniki jego wzbogacania związane z morfometrią i zagospodarowaniem zlewni. Badaniami objęto rzekę Narew w 10 przekrojach pomiarowych na odcinku Bondary – Tykocin oraz rzekę Supraśl, na której wytypowano 6 punktów pomiarowych. W czasie doboru miejsc pobierania próbek osadów dennych za główne kryterium przyjęto obecność ognisk wzbogacania środowiska wodnego w fosfor, głównie oczyszczalni ścieków. Do analiz pobierano również próbki z 17 mniejszych i większych dopływów Narwi. Największe zawartości fosforu wykazano w osadach dennych Narwi (1,31 g · kg^{-1} s.m.), a najmniejsze w osadach Strabelki (0,10 g · kg^{-1} s.m.). Porównanie z innymi badaniami wykazało, że badane osady charakteryzują się typową zawartością fosforu, a lokalnie zwiększone ilości tego składnika są wynikiem ograniczonej wprawdzie, ale istniejącej presji antropogennej. W pracy wykazano, że istnieje zależność zawartości fosforu w osadach dennych od charakteru zlewni poszczególnych rzek, w tym od ilości ścieków odprowadzanych do tych rzek.

Słowa kluczowe: fosfor, osady denne, rzeki, ścieki