Behaviour of Sediments in Water Structures

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Abstract

Bottom sediments are a natural part of aquatic ecosystems. They are increasingly contributing to the deterioration of watercourses and reservoirs and are an undesirable material that causes various serious environmental and technical problems. The most significant problems include the instability of riverbeds, the transport of chemicals, nutrients and organic compounds, the supply of sediments to water reservoirs. Bottom sediments have the ability to bind to their surface various predominantly harmful substances such as heavy metals, radionuclides, nutrients and organic substances. Such sediments pose a risk to the water system in terms of possible remobilization of pollutants into the water.

This paper is focused on the study of behavior of sediments in the Hervartov small water reservoir located in the east of Slovakia and their ability to adsorb phosphorus at the sediment-water interface. The results show that the efficiency of sorption of phosphorus from the aqueous environment by fine and coarse-grained sediments is the highest at the lowest input concentrations of phosphorus in solution, or at low concentrations in surface water above the sediment. At these concentrations, the amount of sorbed phosphorus by fine-grained sediments was up to almost 99%. The coarse-grained sediments sorbed phosphorus at a level of up to 84%. Increasing the concentration of phosphorus in the solution leads to a decrease in the sorption efficiency of the sediment, while at high concentrations of the sorbate, the sorption process is significantly stabilized due to reaching the maximum sorption capacity of bottom sediments.

Key words: sediment, reservoir, sorption, nutrient

1 Introduction

Bottom sediments are an important component of the ecosystem of watercourses and reservoirs. Depending on the type of water, the natural content of substances, the grain composition and also the proportion of anthropogenically influenced components change in sediments. After deposition, they become an important habitat, they are inhabited by macro- and microorganisms, which, among other things, participate in their transformation [1,2,3]. Sediments accumulate substances that can significantly affect the quality of the water with which they are in contact, both in the water body itself and in the waters infiltrating through

the sedimentation layer. For this reason, bottom sediments should be seen as a source of possible pollution of both water types [4].

Sediments deposited at the bottom of reservoirs pose the largest reservoir of phosphorus in most water structures, which can contribute to its high concentrations in water. Because increased concentrations of nutrients (nitrogen and phosphorus) cause water eutrophication, one of the most studied mobilization processes at the sediment-water interface is the study of phosphorus sorption by bottom sediments [5,6].

In the sediment matrix, phosphorus is mostly found in adsorbed (particulate) form [7]. Storage of phosphorus within the sediments potentially reduces eutrophication by reducing its bioavailability [8]. Most of the adsorbed phosphorus is not easily desorbed. The amount that is desorbable decreases with the age of the phosphorus complex adsorbed on the sediment [9]. Desorption of phosphorus from sediments is thought to contribute approximately 10 percent of the total amount of phosphorus in lakes [10]. However, resuspension of phosphorus from the sediment into the water column can be essential in the case when there is no supply of phosphorus from external inlets, or supply is not significant [11]. Other factors and reservoir conditions that may support phosphorus mobilization are critical.

Several authors have studied the phosphorus sorption by sediments, where they found that the sediment grain size, organic content and content of iron and aluminum are the main factors influencing sorption process [12-17].

Therefore, it is necessary to know the behavior of sediments, because quality of sediments is an important indicator of water pollution in water bodies, it allows to detect and locate sources of pollution in the river basin and thus also allows taking the necessary revitalization measures in water basins and reservoirs.

2 Material and methods

Sediment behaviour and the study of their ability to adsorb phosphorus at the sediment-water interface were carried out under laboratory conditions on samples of fine-grained (SF, under 63 μm) and coarse-grained (SC, above 63 μm) in order to demonstrate the influence of different sediment properties (especially their grain size, Fig. 1) on sorption processes. Sediments with different physical and chemical properties were taken from the Hervartov small water reservoir.

Figure 1: Particle size distribution of fine (SF) and coarse-grained (SC) sediments (Mastersizer 2000, Malvern UK)

Air-dry fine-grained and coarse-grained sediments were used to study the phosphorus sorption process at the sediment-water interface. Two grams of sediments were agitated in 50 ml of 0.01 M CaCl_2 solution that is used in adsorption/desorption testing, containing sorbate of various concentrations. As a sorbate, a solution of KH_2PO_4 in the range of 0 ~ 24 mg P/L was used in the experiments. The mixture of sediment and solution was stirred for 24 hours at a constant temperature in order to reach adsorption equilibrium. The suspension was then filtered and the equilibrium phosphorus concentration was determined in the separated aqueous solution using a DR 890 colorimeter (Hach Lange, Germany). The concentrations of total phosphorus adsorbed on the sediment (q_e) were calculated as the difference between the initial concentration of phosphorus in solution (C_0) and its amount in solution after contact with sediment at the end of the experiment (C_e) according to equation (1):

$$q_e = \frac{(C_0 - C_e) \times V}{m} \quad (1)$$

where q_e is the amount of P adsorbed by the sediment after reaching equilibrium (mg P/kg), C_0 is the initial concentration of P in solution (mg/L), C_e is the equilibrium concentration of P in solution (mg P/L), m is the mass air-dry sediment (kg) and V is the volume of the KH_2PO_4 (L) solution.

The following equation was used to calculate the phosphorus removal efficiency from solution at different initial concentrations for both sorbents (2):

$$\% \text{ Sorption} = \frac{(C_0 - C_e)}{C_0} \times 100 \quad (2)$$

3 Results and discussion

The results of the study of the sediment behaviour through the research of their ability to adsorb phosphorus at the sediment-water interface are given in Table 1.

Table 1: Phosphorus content sorbed by fine (SF) and coarse-grained sediment (SC) at equilibrium and their sorption efficiency

C_0 (mg P/L)	$C_{e,SF}$ (mg P/ L)	$q_{e,SF}$ (mg P/kg)	Sorption efficiency, $_{SF}$ (%)	$C_{e,SC}$ (mg P/ L)	$q_{e,SC}$ (mg P/kg)	Sorption efficiency, $_{SC}$ (%)
0	0.13*	3.25*	-	0.08*	2.00*	-
1.18	0.14	26.01	98.90	0.26	22.99	84.02
1.60	0.20	34.90	95.51	0.50	27.56	73.67
6.36	0.53	145.86	93.79	2.77	89.68	57.59
11.12	1.13	249.73	91.00	6.46	116.59	42.61
17.68	4.83	321.90	73.43	12.36	132.90	30.50
23.87	10.99	322.05	54.51	17.45	160.62	27.23

Note: * desorption was observed

The results show that the efficiency of sorption of phosphorus from the aqueous environment

by fine and coarse-grained sediments is the highest at the lowest input concentrations of phosphorus in solution, or at low concentrations in surface water above the sediment. At these concentrations, the amount of sorbed phosphorus by fine-grained sediments was up to almost 99%. The coarse-grained sediments sorbed phosphorus at a level of up to 84%. However, when no sorbate is used, phosphorus is released from the sediment into the water, as shown by the results of leachability tests in our previous research [18]. The amount of phosphorus released into water was recorded at 0.15% for fine-grained and 0.25% for coarse-grained sediment.

Increasing the concentration of phosphorus in the solution leads to a decrease in the sorption efficiency of the sediment, while at high concentrations of the sorbate, the sorption process is significantly stabilized due to reaching the maximum sorption capacity of bottom sediments (Fig. 2).

Maximum sorption of phosphorus by fine and coarse-grained sediments was observed at the highest concentrations of phosphorus in solution [19] with a maximum phosphorus sorption capacity of 325 mg P/kg for fine-grained sediment and 207 mg P/kg for coarse-grained sediment (Fig. 3).

Figure 2: Phosphorus sorption efficiency by bottom sediments depending on their particle size

Figure 3: The development of phosphorus sorption by fine (SF) and coarse grained (SC) sediments in the aquatic environment

The study shows that fine-grained sediment has a higher sorption capacity and can bind

higher amounts of phosphorus than coarse-grained sediment, which is probably related to the granularity and consequently higher specific surface area of fine-grained bottom sediments.

4 Conclusion

In this research, the mechanism of phosphorus adsorption behaviour on the fine and coarse-grained sediments in the Hervartov small water reservoir (in Slovakia) due to the different particle grain size was investigated.

The study demonstrated the ability of phosphorus sorption by sediments. The fine-grained sediment with a higher specific surface area was able to sorb a double amount of phosphorus compared to the coarse-grained sediment with a lower specific surface area. With increasing concentration of added sorbate, the amount of phosphorus sorbed by the sediments decreased, indicating that the sorption efficiency decreased with increasing sorbate concentration. A significantly higher sorption capacity was demonstrated by the fine-grained sediment, which implies that the grain composition and the associated specific surface area play an important role in the sorption properties of bottom sediments.

In terms of the ability of bottom sediments to bind nutrients, it is appropriate to apply them after extraction to the soil, in compliance with the requirements set out in Act no. 188/2003 Coll. on application of sludge and bottom sediments into the land.

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