The quality of bottom sediments in small water reservoirs located in agricultural watersheds

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Abstract. Silting of water reservoirs by sediments detached through soil erosion is a serious water management problem. One of the solutions is direct application of sediments to the soil. The aim of the paper is to monitor the quality of bottom sediments taken from selected water reservoirs in the eastern Slovakia (Hervartov, Nižný Žípov, Byštá) and to evaluate their quality according to legislation. The results showed that the concentrations of total nitrogen, phosphorus and potassium in sediments are higher than in soils taken from the vicinity of reservoirs. Simultaneously, it was confirmed that the sediment in the evaluated reservoirs meets the physicochemical parameters according to the Act No. 188/2003 Coll. for direct application to the soil.

1. Introduction
The permanent transport and sedimentation of particles brought by tributaries and surface runoff from the agricultural land affects not only the quantitative (especially reducing the storage volume of the reservoir, limiting the functionality of reservoirs’ objects and equipment), but also the qualitative characteristics of watercourses and reservoirs. Soil particles washed away by erosion bind substances present in the soil (heavy metals, specific organic substances, etc.) and biogenic elements (especially nitrogen and phosphorus), making them secondary polluters of water resource. Excessive supply of nitrogen and phosphorus to the aqueous environment causes its eutrophication that means accelerated growth of algae and higher forms of vegetation, resulting in undesirable disturbances to the balance of aquatic organisms as well as disturbances to the quality of the concerned waters [1].

The observed declining trend in nitrogen and phosphorus concentrations in European rivers in the long perspective reflects the impact of adopted measures to improve wastewater treatment, reduce the volume of industrial wastewater, minimize the phosphate content in detergents, reduce nitrogen oxide emissions into the atmosphere and measures adopted to reduce nitrate inputs from agriculture at European and national level. With adopted measures, nitrogen and phosphorus pollution from point sources is gradually becoming less significant compared to non-point sources of pollution from agricultural land. The report states that more than 40% of European rivers and coastal water bodies are affected by diffuse pollution from agriculture, while 20 to 25% are at risk from point source pollution [2]. Despite improvements in water quality in recent decades, nutrient concentrations in water remain high in many places. Prognosis for the next 20 years suggest that in regions with intensive agricultural production, diffuse nitrogen and phosphorus pollution will still be high, resulting in persistent eutrophication problems [3].

In addition to monitoring water quality, in recent decades the monitoring and management of sediment quantity and monitoring of sediment quality parameters has been at the forefront of interest practically throughout Europe. Monitoring of element concentrations in river and reservoir sediments from various areas is of great interpretative importance, e.g. when evaluating the background concentrations...
of individual indicators, the degree of anthropogenic sediment loading by the distribution of various pollutants, erosion processes in the relevant watershed, etc. When evaluating sediments, however, it is necessary to take into account the specifics and conditions of the natural environment of the territory. The assessment of the degree of contamination risk must therefore be taken into account in relation to the estimated natural resources influencing the chemical composition and sediments’ quality [4]. It is also important to monitor the quality of sediments in terms of their subsequent management, especially after dredging [5]. Since bottom sediments are mostly composed of eroded soil, which has a higher proportion of nutrients than the soil on the surrounding land from which it was washed away, attention can be focused on their biotic use. This should be understood as the direct application of bottom sediments to soils while respecting the regulations for the protection of environmental components.

2. Material and methods

The paper focuses on the monitoring and evaluating the bottom sediment quality in three small water reservoirs located in agricultural watersheds in the eastern Slovakia (Figure 1). The reservoirs were built mainly for the purposes of accumulating water to irrigate the surrounding agricultural land, fish farming, retention of large waters and suburban recreation. The basic reservoirs’ attributes according to Slovak technical standard STN 73 6824 [6] such as their total capacity and depth, are given in Table 1.

![Figure 1. Location of studied small water reservoirs.](image)

| Name of reservoir | District | Stream       | Altitude (MSL) | Average depth (m) | Surface area (m) | Total reservoir capacity (m³) |
|-------------------|----------|--------------|----------------|-------------------|------------------|-------------------------------|
|                   |          |              |                |                   |                  | Dead storage (m³) | Active storage (m³) | Flood reserve (m³) |
| Hervartov         | Bardejov | Tisovec      | 343.00         | 3.5               | 2.20             | 1 215             | 60 310            | 10 603            |
| NižnýŽipov        | Trebišov | Žipov creek  | 139.00         | 2.5               | 6.50             | 28 000            | 120 000           | 30 000            |
| Byšta             | Trebišov | Byšta       | 198.50         | 3.7               | 4.33             | 10 000            | 130 000           | 12 500            |

Table 1. Basic characteristics of small water reservoirs.
To evaluate the quality of bottom sediments, soil, water and sediment samples were taken during summer season. Soil samples were taken from agricultural land or parts thereof located in the immediate vicinity of the reservoirs. Average soil samples were composed of at least 30 point samples taken to a depth of 0.30 m. The minimum weight of the average sample was 5 kg. For bottom sediments, mixed samples consisting of five point samples were taken from the reservoirs. The sampling sites were located in the area of the dam because of the maximum deposition of silty / clay fraction (particles < 0.063 mm). The weight of the sediment samples for chemical analysis was about 3 kg [7]. Soil and sediment samples were taken in plastic bags. Subsequently, under laboratory conditions, their treatment consisted in crushing large lumps in the wet state and subsequent drying at laboratory temperature. Later, the dry samples were crushed and thoroughly homogenized. Water samples were taken at the reservoir dam in accordance with the Slovak technical standard STN EN ISO5667-4 [8].

Because studied reservoirs are located in agricultural watersheds, where water and sediment quality is affected by nonpoint source pollution from the agricultural production areas, the samples were preferentially analyzed for nutrients. Analyzes on soil samples were performed to determine total nitrogen (N), phosphorus (P) and potassium (K), while chemical analyzes in bottom sediment samples were realized in accordance with the Act of the National Council of the Slovak Republic No. 188/2003 Coll. [9]. Total nitrogen and phosphorus, which contribute to surface water eutrophication, were analyzed in the water samples. Soil, sediment and water samples were analysed in accredited laboratory of State Geological Institute of Dionyz Štúr Spisšská Nová Ves.

3. Results and discussion

To assess the environmental impact of sediments on the quality of aquatic environment, it is necessary to determine the load on the aquatic environment by chemical substances - nutrients, which come mainly from diffuse sources of pollution and cause eutrophication of surface waters. From the water management point of view, sediments are also of great importance, because the quantity and quality of sediments is also related to the question of their further use or deposition. Since bottom sediments are mostly composed of eroded soil, which has a higher proportion of nutrients than the soil on the surrounding land from which it was washed away, attention can be focused on their biotic use [9]. This should be understood as the direct application of bottom sediments to soils while respecting the regulations for the protection of environmental components.

The analysed concentrations of total N, P, K in soil samples are given in Table 2.

| Parameter | Unit | Hervartov | Nižný Žipov | Byšta |
|-----------|------|-----------|-------------|--------|
| \( N_{\text{total}} \) | (%)  | 0.08      | 0.07        | 0.09   |
| \( P_{\text{total}} \) | (%)  | 0.069     | 0.03        | 0.028  |
| \( K_{\text{total}} \) | (%)  | 1.80      | 1.65        | 1.30   |

Tables 3 and 4 show the results of the chemical analyses of bottom sediment and water samples taken from studied reservoirs. To assess the content of contaminants in bottom sediments, limit values according to [9] (Table 3) were used. The regulation of the Government of the Slovak Republic No. 269/2010 [10] was used to assess the water quality (Table 4). A comparison of the concentrations of total N, P, K in the agricultural soil located in the immediate vicinity of the reservoir and in the sediments deposited in the reservoir shows that bottom sediments contain a higher nutrient content than the original soil, which is in accord with literature [11]. This is mainly because nutrients are found in large amounts in the upper layers of the soil and fine fractions of the soil are easily washed away [12]. It has been shown that nutrients, especially phosphorus, are adsorbed by fine particles with a larger surface area [13]. The results of the study also show that due to higher concentrations of nutrients in bottom sediments compared to eroded soil and satisfactory requirements for the limit content of hazardous substances in
bottom sediments specified in [9] (dry matter content, organic content, pH values, content of hazardous substances) it is possible to consider their application to agricultural land [14]. However, in addition to the hygienic requirements for sediments, (concentrations of hazardous substances below the limit), other indicators at the site of application to the soil must be met, such as the granularity of the sediment, the slope of the terrain, the groundwater level, etc.

### Table 3. Chemical analyses of bottom sediment samples according to Act No. 188/2003 Coll.

| Parameter               | Unit | Hervartov | Nižný Žipov | Byšta | Limit value (Act No. 188/2003) |
|-------------------------|------|-----------|------------|-------|-------------------------------|
| Sediment pH             | (-)  | 7.39      | 7.39       | 7.44  | > 5                           |
| Dry matter (105°C)      | (%)  | 97.75     | 63.94      | 67.25 | -                             |
| Organická hmota (%)     |      | 3.01      | 1.20       | 1.80  | -                             |
| N (%)                   |      | 0.20      | 0.09       | 0.11  | -                             |
| P (%)                   |      | 0.09      | 0.031      | 0.035 | -                             |
| K (%)                   |      | 2.05      | 1.78       | 1.41  | -                             |
| Mg (%)                  |      | 0.77      | 0.61       | 0.32  | -                             |
| As (mg/kg)              |      | 9         | 9          | 9     | 20                            |
| Cd (mg/kg)              |      | < 0.3     | < 0.5      | < 0.5 | 10                            |
| Cr (mg/kg)              |      | 100       | 87         | 85    | 1000                          |
| Cu (mg/kg)              |      | 25        | 19         | 11    | 1000                          |
| Hg (mg/kg)              |      | 0.09      | 0.03       | 0.04  | 10                            |
| Ni (mg/kg)              |      | 39        | 29         | 15    | 300                           |
| Pb (mg/kg)              |      | 26        | 24         | 25    | 750                           |
| Zn (mg/kg)              |      | 136       | 76         | 56    | 2500                          |
| AOX (mg/kg)             |      | 31.3      | < 10       | < 10  | 500                           |
| PCB (mg/kg)             |      | < 0.01    | < 0.01     | < 0.01| 0.8                           |
| PAU (mg/kg)             |      | 1.15      | < 0.05     | 0.19  | 6                             |

### Table 4. Chemical analyses of water samples.

| Parameter | Hervartov (%) | Nižný Žipov (%) | Byšta (%) | Limit concentration (Regulation no. 269/2010) mg/L |
|-----------|---------------|-----------------|-----------|-----------------------------------------------|
| N<sub>total</sub> | 2.08          | 1.4             | 2.0       | 9                                             |
| P<sub>total</sub>  | 0.2           | 0.07            | 0.15      | 0.4                                           |

The results of the chemical analysis of the water showed that the requirements for surface water quality are met. This situation may be influenced by the fact that the studied sediments act as an adsorbent of phosphorus from the aqueous environment, which was also demonstrated in a previous researches conducted by Junakova et al. [13, 15]. The presence of organic matter in the sediment may contribute to lower concentrations of total nitrogen in the water, which may indicate that most of the nitrogen content in the sediment comes from the organic matter bound to the sediment [16]. According to [13], the evaluation of the quality of bottom sediments from the Hervartov water reservoir shows that the presence of nutrients in the sediments does not affect the water quality; on the contrary, the sediments contribute to their accumulation from the reservoir water environment. Despite this fact, some of the pollutants bound in the fine fractions of sediments can be released under specific conditions due to remobilization processes and affect the quality of the lower layers of the accumulated water.
4. Conclusions
Knowledge about the chemical composition of bottom sediments is of great environmental importance, because sediments resulting from erosive runoff from agricultural soils play an important role in the transport of pollutants into the aquatic environment due to remobilization processes. In addition, they are also of great importance from a water management point of view, as the quantity and quality of sediments is also related to the question of their further use or deposition.

The article summarizes the results of bottom sediments quality monitoring in three small water reservoirs located in agricultural watersheds in the eastern Slovakia (Hervartov, Nižný Žípop, Byšt). Because the quality of sediments in terms of the concentration of hazardous substances and their amount is related to the quality of eroded soils and may affect water quality and subsequently affect their further use or deposition, research was also focused on monitoring water and soil quality on surrounding land.

Results showed that the concentrations of total nitrogen, phosphorus and potassium in monitored reservoirs’ sediments are higher than in soils taken from the vicinity of reservoirs. The analyzes of physicochemical parameters of sediments indicate the possible direct application of monitored sediments to agricultural land.

Although the use of sediments as fertilizers in agriculture partially solves the problem of sediment management, it is also necessary to pay attention to the procedure in their application in order to really improve the soil quality. Despite favorable indicators of sediment quality, which meet the applicable legal and technical regulations for their application to the soil, there is always a risk of damage to soil quality and subsequent damage to soil organisms. As it is not possible to analyze the hundreds of chemical individuals that can potentially occur in contaminated sediments, it is ultimately not possible to directly estimate the synergistic effects of these substances on the environment.

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