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Analysis of Selected Nutrient Contents in Bottom Sediments of the Ostrowy Water Reservoir using the GIS System

Analiza zawartości wybranych substancji biogennych w osadach dennych zbiornika wodnego Ostrowy z wykorzystaniem systemu GIS

The aim of the study was to evaluate the contents of phosphorus and nitrogen in bottom sediments of the Ostrowy water reservoir. Furthermore, concentrations of aluminium, iron, organic matter were determined and the depth was measured. The evaluation was made using spatial modelling to obtain spatial distributions of the elements studied. Aluminium and nitrogen concentrations were classified according to the Persaud criteria. An attempt was also made to determine the possible relationships between nitrogen and phosphorus, and the content of organic matter, iron and aluminium in the material studied. Bottom sediment samples were collected based on a regular measurement grid from 31 points in the area of the Ostrowy water reservoir. The material was subjected to laboratory analysis, with the contents of elements tested ranging from 0.25 to 9.76 g/kg for total nitrogen, 0.04 to 4.50 g/kg for total phosphorus, 0.48 to 31.40% for organic matter, 0.57 to 12.64 g/kg for aluminium, and 1.70 to 30.70 g/kg for iron. Based on the Persaud classification, the major area of the reservoir is characterized by moderate and high risks resulting from the nitrogen content and low and moderate risk due to the presence of phosphorus. The correlations were also examined between organic matter and total nitrogen ($R^2 = 0.82$), total nitrogen and Fe ($R^2 = 0.79$), total nitrogen and Al ($R^2 = 0.74$), organic matter and Fe ($R^2 = 0.82$), organic matter and Al ($R^2 = 0.79$), total phosphorus and Fe ($R^2 = 0.88$), and total phosphorus and Al ($R^2 = 0.74$). The GIS tools used to generate spatial distributions have proven to be extremely useful in environmental research. Using geoinformation, maps of spatial distributions of the elements studied were generated (the method of interpolation of inverse distance weighted was used). Bottom sediments of water reservoir in Ostrowy are characterized by higher contents of nitrogen and phosphorus in bottom part and lower in northern part. The distributions made it possible to accurately assess the studied area and can be effective in planning of monitoring and reclamation activities in the area of the Ostrowy water reservoir.

Keywords: **bottom sediments, spatial distribution, nutrients**

Introduction

Nitrogen and phosphorus are the main nutrients that significantly contribute to the increased fertility of water bodies and the rapid progress of eutrophication. These substances are essential for the proper functioning of aquatic flora and fauna.

However, their excessive amounts lead to the significant growth of algae and aquatic plants which adversely affects the functioning of aquatic ecosystems. Nitrogen and phosphorus enter both surface waters and bottom sediments, mainly from point sources (e.g. discharge of municipal and industrial sewage) and area sources of pollution (e.g. surface runoff from fertilised fields, precipitation) [1, 2].

Eutrophication is a common phenomenon in inland water ecosystems. This process occurs in surface waters, but it mainly concerns standing waters and objects characterised by matter accumulation properties. The increase in the fertility of reservoirs is part of the natural processes occurring in them and is a manifestation of the natural evolution of all reservoirs. However, it happens that accelerated eutrophication of many objects results from a broad range of anthropogenic activities [3-5].

Nutrients (such as nitrogen, phosphorus) are accumulated mainly in bottom sediments rather than in the water itself. Bottom sediments are characterised by a high capacity of storage of nutrients entering the reservoir from the drainage basin and those already present in the water. The 10 cm sludge layer may contain more than 90% of the phosphorus present in the reservoir. In most cases, under favourable conditions, nutrients can be released back into the water, posing a potential threat to the entire ecosystem [5-8]. In Poland, the majority of nitrogen and phosphorus compounds migrate to surface waters and groundwater due to agricultural activity. It is estimated that about 50 to 60% of nitrogen and phosphorus entering the Baltic Sea comes from agricultural sources [1, 2, 8, 9].

Organic and inorganic forms of phosphorus in bottom sediments are converted into orthophosphates, whereas nitrogen compounds change into ammonium, nitrite or nitrate. A thin layer (from a few millimetres to a few centimetres) is formed in sediments, with prevailing processes involving anaerobic bacteria. The decomposition of organic matter by bacteria is one of the basic mechanisms that influence the level of nutrients in the reservoir. When the optimum nutrient load for a given object is exceeded, the so-called supply, or internal import, is started. This phenomenon manifests itself in the release of nutrients, mainly phosphates, accumulated in the matter lying at the bottom of water reservoirs. The transformation of phosphorus in the aquatic environment depends on many factors, mainly on water quality (redox potential, pH, content of Fe, Al, and Ca) [6, 8, 9]. Different levels of nutrient accumulation in bottom sediments are also determined by the environmental conditions, morphology and hydrology of the reservoir (flow fluctuations and constant water level). However, most nutrients are accumulated in bottom sediments in the deepest parts of water reservoirs, and in parts characterized by water stagnation, within zones near agricultural areas or in places where fine-grained fractions dominate in the deposited material composition [9].

Release of nutrients from bottom sediments to water depths is particularly noticeable during summer stagnation. This mechanism takes place mainly with the participation of bacteria and penetrating water with such connections as Fe-P and Al-P under anaerobic conditions. The most important processes related to phospho-

rus retention in bottom sediments include sorption and binding this element by iron hydroxides and calcium carbonates and autogenic mineral formation [8-11].

The aim of the study was to analyse phosphorus and nitrogen content in bottom sediments of the Ostrowy reservoir and to evaluate their potential impact on benthic organisms. An attempt was also made to determine the relationships between the concentrations of phosphorus and nitrogen and: content of organic matter, aluminium, iron accumulated in the bottom sediments of the reservoir, and the depth of the object. The GIS system was used to generate spatial distributions of the elements analysed.

1. Methodology and area of research

The Ostrowy reservoir is located between the villages of Ostrowy and Borowa in the Polish gmina of Miedźno. This water reservoir should be classified as a small water reservoir due to its area of 39 ha. The main inflow to the reservoir is the Biała Oksza River. This river supplies waters from a 160 km^2 catchment area, which consists of 11 villages of about 7.5 thousand inhabitants. The dominant sector in the area of the Biała Oksza River basin is agriculture, with majority of small farms. Due to its recreational and tourist function, the reservoir in question is very popular among local residents [12].

Sampling of bottom sediments of the Ostrowy reservoir was carried out in August 2016. Using the ArcGIS software, a network of measurement points was developed in the form of a grid composed of 31 measurement points. Using the GPS system, the planned network was mapped and bottom sediment samples were taken. Samples of bottom sediments were collected at 31 measurement points from the surface layer of sediment (up to 15 cm depth of the sediment). The material for the study was collected using a special Van Veen grab sampler (KC Denmark) [5, 8, 12].

The collected samples of bottom sediments were dried in air-dry conditions and then initially sifted through a sieve with a mesh diameter of 2 mm. They were successively dried in a dryer at 105ºC to constant mass and ground in a vibration mill to a fraction of sediments with particle diameter < 0.2 mm. Three samples were prepared for analyses from each measurement point. Samples of bottom sediments were tested for contents of total phosphorus, Kjeldahl nitrogen, iron, aluminium, and organic matter. Spectrophotometric method with ammonium molybdate was used to determine the content of total phosphorus according to EN ISO 6878: 2004. Mineralization was carried out at 180°C for 30 minutes using a high-pressure microwave mineralizer (Berghof, Germany). Total nitrogen content was determined by the Kjeldahl method using distillation according to the Polish Standard PN-ISO11261:2002, and mineralization at 350°C with concentrated sulphuric acid. The weight method according to PN-ISO 11465:1999 standard was used to determine the content of organic substances. The total content of iron (Fe) and aluminium (Al) was also determined in bottom sediments. Aqua regia was used for their

extraction (a mixture of concentrated hydrochloric and nitric acids at a volumetric ratio of 3:1) [5, 7-9].

Maps showing the spatial distribution of aluminium content (Fig. 1), iron (Fig. 2), total phosphorus (Fig. 3), Kjeldahl nitrogen (Fig. 4), percentage of organic matter (Fig. 5) and depth (Fig. 6) were interpolated by means of inverse distance weighting [12, 13]. The analyses were conducted using the Geostatistical Analyst application, which is an integrated part of ArcGIS software (ESRI).

The evaluation of phosphorus and nitrogen contents and assessment of their potential effect on aquatic organisms was made using the Sediment Quality Standards (SQS). This classification includes three different grades of nitrogen and phosphorus concentrations in bottom sediments. At the first degree, the negative impact on benthic organisms is not considered to exist, the second degree indicates a moderate risk, while the third degree indicates a high risk (Table 1) [14].

Table 1. **Classification of potential ecological risk caused by total nitrogen and phosphorus with indication of risk levels [14]**

Class	Total nitrogen g/kg	Total phosphorus g/kg	Risk level
I	< 0.55	< 0.60	low
II	0.55÷4.80	0.60÷2.00	moderate
III	≥ 4.80	≥ 2.00	high

Statistical analysis of laboratory test results was performed by means of Statistica software. At this stage, the arithmetic mean, range of variation (minimum, maximum), kurtosis and asymmetry coefficient (skewness) were determined (Table 2). The coefficient of determination was also computed from ArcGIS (R^2) software between the determined contents of individual elements in bottom sediments.

2. Results and discussion

The bottom sediments of the reservoir examined in the study were characterized by a relatively high content of total phosphorus. It ranged from 0.25 to 9.76 g/kg. Depending on the place of sampling, the values of total nitrogen content in the bottom sediments of the Ostrowy reservoir varied. The results ranged from 0.57 to 12.64 g/kg (Table 2).

Based on the initial analysis of the data, it was found that all examined elements were characterized by similar results of descriptive statistics:

- large right-hand asymmetry (high asymmetry coefficient value),
- high standard deviation from the mean value,
- mean value higher than the median,
- a large difference between the maximum and minimum values,
- leptokurtic distribution: values are more concentrated than in normal distribution,
- presence of outliers.

In the next step, coefficients of determination between the results of individual determinations performed in bottom sediments were evaluated (Table 3). The obtained values indicate a significant correlation of the concentration of nitrogen with the contents of organic matter and phosphorus, and a strong correlation between the concentrations of aluminium and iron. All the parameters analysed (except for depth) were characterized by a significant spatial dependence (coefficient of determination above 0.6). There were no correlations between the levels of concentration of the analysed elements and the results obtained for the depth.

Table 2. **Statistics of total phosphorus, Kjeldahl nitrogen, Al, Fe and OM contents in bottom sediments of the Ostrowy Reservoir**

Parameter	Mean	Median	Minimum	Maximum	Standard Deviation	Skewness	Kurtosis
Al, g/kg	4.10	3.12	0.57	12.64	2.99	1.31	1.19
Fe, g/kg	8.20	4.86	1.70	30.70	7.86	1.71	2.33
Organic matter, %	8.68	4.27	0.48	31.40	8.55	1.00	0.09
Phosphorus, g/kg	0.69	0.28	0.04	4.50	1.02	2.72	7.34
Nitrogen, g/kg	3.17	2.00	0.25	9.76	2.84	0.90	–0.42

Table 3. **Coefficients of determination between nitrogen, phosphorus, organic matter, aluminium, iron and depth for the Ostrowy water reservoir**

	N	Organic matter	Al	Fe	Depth
Organic matter	0.82	–	–	–	–
Al	0.74	0.79	–	–	–
Fe	0.79	0.82	0.91	–	–
H (depth)	0.08	0.01	0.00	0.00	–
P	0.64	0.69	0.72	0.88	0.01

Iron content in the bottom sediments of the Ostrowy reservoir ranged from 1.70 to 30.70 g/kg, whereas aluminium content was from 0.57 to 12.64 g/kg. Both the coefficients of determination and spatial distributions (Figs. 1 and 2) demonstrated strong correlations between the concentration levels of these two elements. Their high content is observed in the southern part, while lower concentrations were found in the bank and northern zones of the analysed reservoir [8, 15-18].

According to the SQGs classification, the entire reservoir (except for points 5, 11 and 12) is characterised by a moderate and high level of risk caused by nitrogen content in bottom sediments. In the case of phosphorus content, on the other hand, moderate and low risk prevails, with high risk point outliers (points 25, 26, 32).

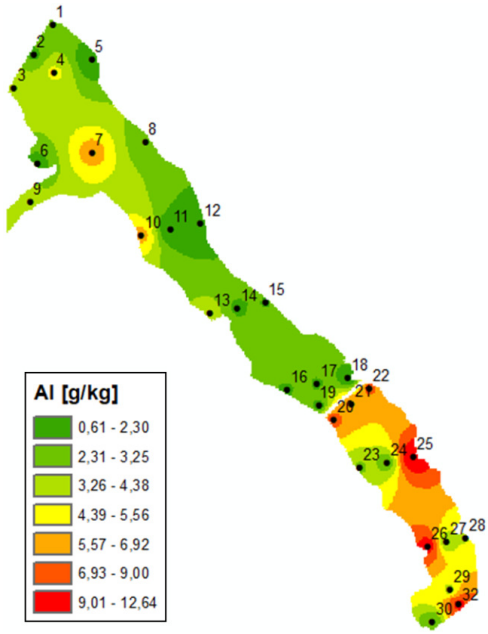

Fig. 1. Spatial distribution of aluminium in bottom sediments of the Ostrowy Reservoir

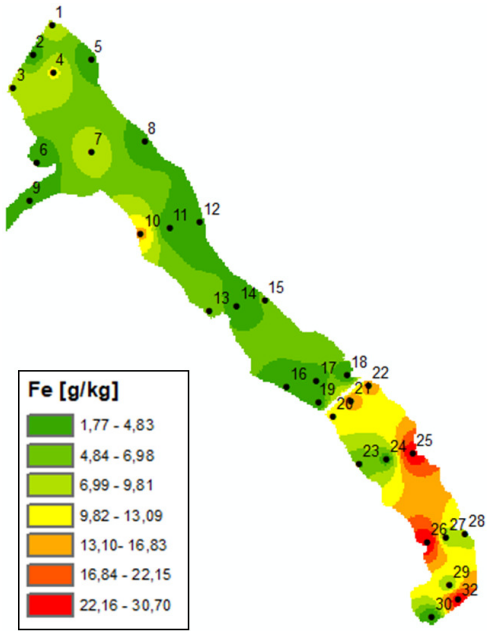

Fig. 2. Spatial distribution of iron in bottom sediments of the Ostrowy Reservoir

Anthropogenic pollution associated with surface runoff (discharge of municipal wastewater, introduction of water from outside the catchment area into rivers, crop protection agents and fertilisers) is identified as a potential cause of high concentrations of total phosphorus, total nitrogen, organic matter, iron, and aluminium [5, 8, 19, 20]. Currently, the Ostrowy reservoir is mainly used for recreation, and it is also a popular object used for angling. Its pollution can have a significant effect on the flora and fauna of the facility and consequently on human health. For this reason, it should be subjected to systematic tests related to the monitoring of the condition of its waters and bottom sediments.

The distribution of total phosphorus and Kjeldahl nitrogen also depended on the spatial distribution of aluminium and iron (Figs. 1-4), i.e. metals which are capable of binding phosphorus. This finding is confirmed by a noticeable correlation between these elements (high values of coefficients of determination, see Table 3). A similar relationship was observed in the case of total phosphorus and iron, with coefficient of determination (R^2) of 0.88, whereas this value for nitrogen and iron was 0.79 (Table 3). Increased phosphorus and nitrogen contents in the bottom sediments of the Ostrowy reservoir may indicate that the tested reservoir and its drainage basin are exposed to harmful anthropogenic activity [8]. The direct catchment area of the Biała Oksza River is located near agricultural areas. With surface runoff, fertilizers, crop protection agents and sewage sludge flow into its waters. Therefore, an increased level of contaminants was observed in the inlet part of the reservoir. The lowest concentrations of both nitrogen and phosphorus were found in the bank and northern zones.

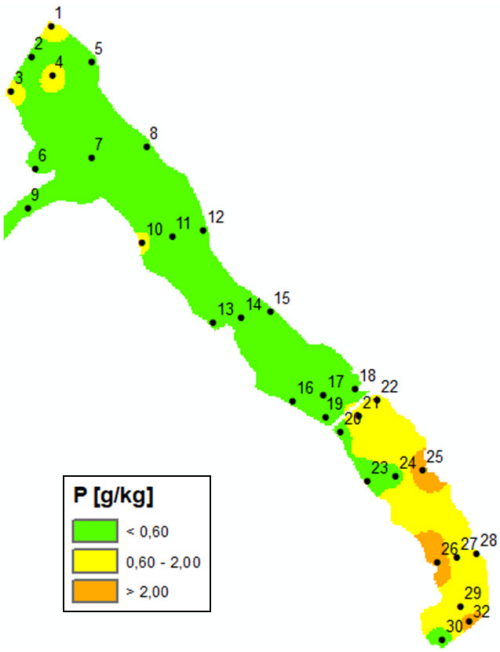

Fig. 3. Spatial distribution of total phosphorus in bottom sediments of the Ostrowy Reservoir

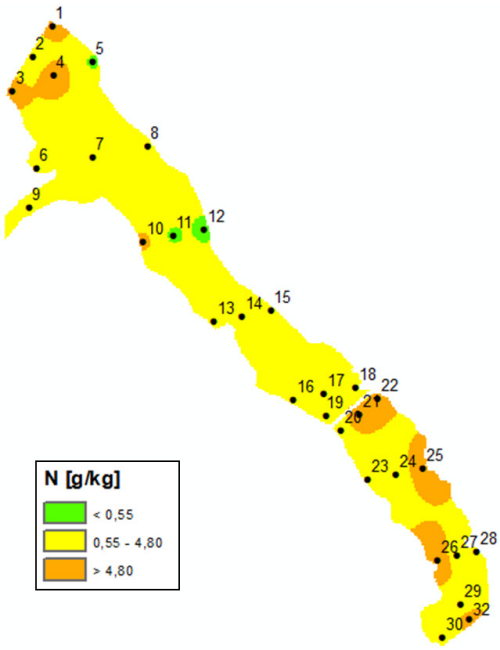

Fig. 4. Spatial distribution of total nitrogen in bottom sediments of the Ostrowy Reservoir

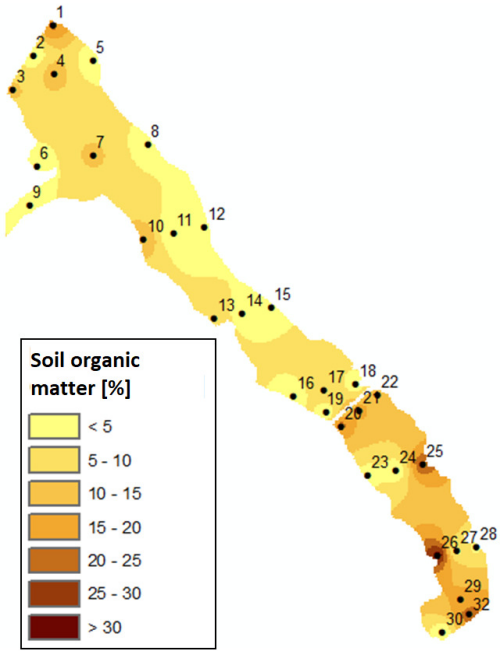

Fig. 5. Spatial distribution of organic matter in bottom sediments of the Ostrowy Reservoir

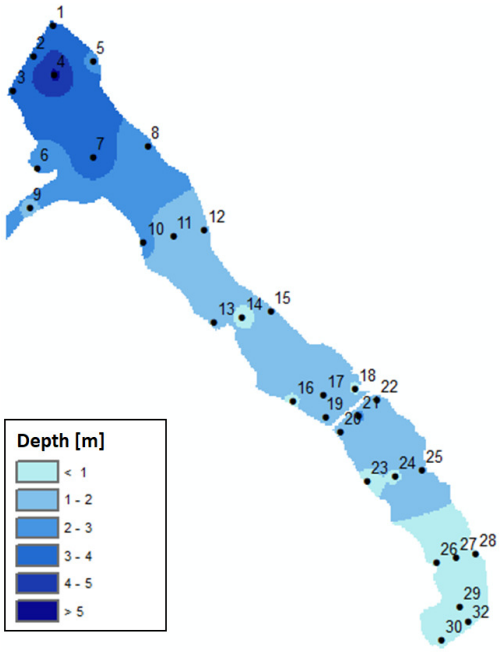

Fig. 6. Spatial distribution of depth of the Ostrowy Reservoir

Conclusions

The results obtained in the study and their analysis lead to the following conclusions:

1. Concentrations of phosphorus (0.04÷4.50 g/kg) and nitrogen (0.25÷9.76 g/kg) in the bottom sediments of the Ostrowy reservoir are characterised by a very diversified spatial distribution. The values of the parameters analysed (phosphorus, nitrogen, aluminium, iron and organic matter) are characterized by a significant range of data. The highest concentration was found in the southern part of the reservoir, while the smaller one in the northern zone.
2. The pilot research presented in this study may serve as a basis for planning works to identify harmful impacts of human activity, determine objectives for preventing these impacts, and establish appropriate water management principles.
3. The presented study indicated the need to monitor the condition of small water reservoirs. Currently, the Ostrowy Reservoir has a recreational function and therefore it should be constantly monitored for the health risks for people staying near the reservoir.
4. It has been confirmed that the high content of aluminium and iron favours the accumulation of nutrients in bottom sediments. This is evidenced by the values of coefficients of determination for individual elements (at the level of 0.6÷0.8).
5. The applied GIS system and related analyses are extremely important to conducting environmental research. They make it possible to obtain precise maps of the spatial distribution of the examined parameters, which may directly contribute to the analysis of pollution sources and conducting regular monitoring.
6. Most of the samples were characterised by moderate and high risk to aquatic organisms due to nitrogen content and low and moderate risk due to the level of nitrogen concentration in the bottom sediments of the Ostrowy reservoir.
7. No correlations were found between the depth of the reservoir and the concentration of the examined elements.

Acknowledgements

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Streszczenie

Celem badań była ocena zawartości fosforu i azotu w osadach dennych zbiornika wodnego Ostrowy. W badanym materiale oznaczono również stężenie glinu i żelaza oraz zawartość materii organicznej. Przedstawiono także wyniki dotyczące pomiaru głębokości. Podjęto próbę wyznaczenia relacji między poziomem stężenia azotu i fosforu a zawartością substancji organicznej, żelaza i glinu w materiale badawczym. Próbki osadów dennych pobrano na podstawie regularnej siatki pomiarowej zlokalizowanej w obrębie zbiornika wodnego Ostrowy. Pozyskany materiał został poddany badaniom laboratoryjnym, zakres wartości poszczególnych elementów wynosił: azot całkowity 0,25÷9,76 g/kg, fosfor całkowity 0,04÷4,50 g/kg, zawartość materii organicznej 0,48÷31,40% suchej masy osadu dennego, glin 0,57÷12,64 g/kg, żelazo 1,70÷30,70 g/kg. Na podstawie klasyfikacji umożliwiającej ocenę potencjalnego wpływu zanieczyszczonych osadów na organizmy wodne stwierdzono, że przeważająca część zbiorni-

ka charakteryzowała się umiarkowanym oraz wysokim stopniem zagrożenia (ze względu na zawartość azotu) oraz niskim i umiarkowanym (ze względu na zawartość fosforu). Przy wykorzystaniu metody wagowanej odwrotnej odległości wyinterpolowano mapy przestrzennego rozkładu badanych elementów. Wykorzystane narzędzia GIS okazały się niezwykle przydatne w badaniach środowiskowych. Rozkłady przestrzenne umożliwiły dokładną analizę zawartości poszczególnych elementów oznaczonych w osadach dennych badanego obiektu oraz stanowiły podstawę do zaplanowania monitoringu oraz działań rekultywacyjnych na obszarze zbiornika Ostrowy.

Słowa kluczowe: **osady denne, rozkład przestrzenny, substancje biogenne**