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ASSESSMENT OF HYDRAULIC, HYDROLOGICAL AND PHYSICOCHEMICAL FACTORS AFFECTING VEGETATION DEVELOPMENT IN DAM RESERVOIR WITH SEPARATED INLET ZONE - STARE MIASTO (CENTRAL POLAND) RESERVOIR AS A CASE STUDY

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ABSTRACT

Environmental factors affecting vegetation development in the newly constructed lowland reservoir Stare Miasto located in the central part of Poland, were determined. The reservoir is divided into two parts and the majority of sediments are deposited in the upper part. The vegetation in both parts of the reservoir was surveyed. Moreover, extensive environmental dataset, including hydraulic and hydrological parameters, physical and chemical features of water and sediment grain size, was completed. The influence of various abiotic factors on littoral vegetation, including both submerged and emerged macrophytes, was analysed. We have found that zones of the reservoir had different hydraulic and hydrological conditions, different water quality and various sediment transport intensity. The botanical survey showed that the vegetation was very abundant and strongly differentiated. More diverse and abundant vegetation was detected in the upper zone. The downstream zone showed lower abundance of vegetation cover and lower biodiversity. The specific construction of the reservoir and regular water management were found the reasons for water vegetation diversity. More stable conditions in the upper zone, such as constant water level and lower depth, increased the diversity of vegetation and stimulated its abundance.

KEYWORDS:
lowland reservoir, succession of species, biodiversity, abiotic factors

INTRODUCTION

The construction of a dam on a river considerably transforms the environment downstream as well as upstream of the hydro-structure. Most substantial changes concern the hydraulic conditions, water velocity, depths, and intensity of sediment transport along the watercourse [1, 2, 3]. Variations in the channel capacity can be detected on the basis of the hydrologic regime indicators, e.g. inundation frequency and duration [4, 5, 6]. Moreover, flow modifications cause changes in water quality in the river, in the littoral zone and the interior part of the reservoir [7, 8, 9, 10]. The size of area affected depends on the reservoir location and its dimensions [11].

Reservoirs demonstrate a lot of features distinguishing them from natural lakes. They differ from lakes by the asymmetry of the bowl, which is the deepest at the dam front and shallowest on an inlet, they are characterised by a different ratio of the catchment area to the water surface, a shorter water retention time, frequent changes in water level and lower content of organic compounds in bottom sediments [10, 12, 13]. The ecosystem created by the impounding reservoir should be treated as a creative secondary succession which results in formation of a specific place ultimately different than the original one. Initiation of a new system triggers a chain of reactions aiming at maintaining the matter cycle and flow of energy [13]. Due to their specific structure and different influence of abiotic factors, the reservoirs are characterised by different rates and directions of succession [12].

Building dams strongly affects the habitat conditions of aquatic plants and animals [6, 7, 12, 14, 15, 16, 17, 18]. These changes include (1) fragmentation of habitats, (2) decrease in biodiversity in riverside, (3) decrease in abundance of native species and (4) appearance of new species. Construction of the reservoir influences also total biomass of plants in the river downstream of the dam and its temporal variability [12]. The impact of the river damming on the river vegetation was the subject of many studies but specific bio-geomorphological relations between the hydrological regime and sediment transport on the development of macrophytes still raise much concern [19].

The growth of water plants in the reservoir is spatially and temporally diverse. It depends on many environmental factors. In natural lakes the key factors impacting the growth of vegetation in the littoral zone are morphological measures of bowl (area, depth, slope and exposition of the banks), age, water transparency, nutrient availability, ice phenomena in the lake and banks erosion [20, 21, 22]. In the reservoirs in which the headwater is regulated, the conditions are different [23]. When the reservoir is built, the development of species such as algae, zooplankton, plants, fish, birds and mammals, can go in different directions [18]. Their development can be very slow but sometimes favourable conditions for the littoral vegetation grow can occur in some parts of reservoirs more sheltered from mechanical stress. At such sites the littoral vegetation may cover large parts of the eulittoral zone, whereas the vegetation can be very scarce on areas delimited by the seasonal maximum and minimum water levels [24]. The vegetation development can be strongly influenced by water management but this problem has not been investigated much [23].

The aim of this study is to identify the abiotic factors determining the directions and rate of aquatic vegetation development in various parts of reservoirs with a separated zone for sediment deposition. Our analysis is based on the case study of Stare Miasto reservoir which is a lowland aquatic body in the central Poland. The habitat conditions in the reservoir are extensively described and moreover the impact of damming on the hydraulic and hydrological conditions of the reservoir tributary is presented. The development of the submerged and emerged macrophytes is analysed.

STUDY SITE DESCRIPTION

The Stare Miasto reservoir is located in the Powa river watershed in the central part of Poland. The Powa river is the third-order river and its length is 48.2 km. Its catchment area has a rural character, with agricultural land occupying 68.0% of the area, while 27.6% is occupied by forests. The share of the other land use types is marginal: only 3.1% is taken by urban areas, 0.7% by wetlands and 0.6% by surface waters. The entire watershed area of this river is 344.6 km^2, in which the watershed of Stare Miasto covers 299.7 km^2.

The reservoir was built in 2006. The Stare Miasto reservoir is a multipurpose reservoir designed for flood control, irrigation, recreation and flow augmentation. Since 2013 it has been also used for hydroelectric power generation. The area of inundation during normal conditions is 90.7 ha and its length is 4.5 km. The depth of the reservoir varies from 1.2 m in the upper part to 5.7 m near the main dam. The total storage capacity of the reservoir is 2.159×10^6 m^3, but its effective water storage is 1.216×10^6 m^3. The water surface level elevation in the main part of reservoir varies from the minimum elevation of 92.70 m a.s.l. to 94.00 m a.s.l.. Normal water level is 93.50 m a.s.l.. For such conditions the depths are varying from 1.0 to about 4.0 meters in the main part. The average depth is 2.4 meter. In the initial part a constant water level of 93.50 m a.s.l. is kept. The maximum depth in this part is observed close to the internal dam and it is equal to about 1.5 meter. The Stare Miasto reservoir is divided into the main and upper parts by a dam (Fig. 1).

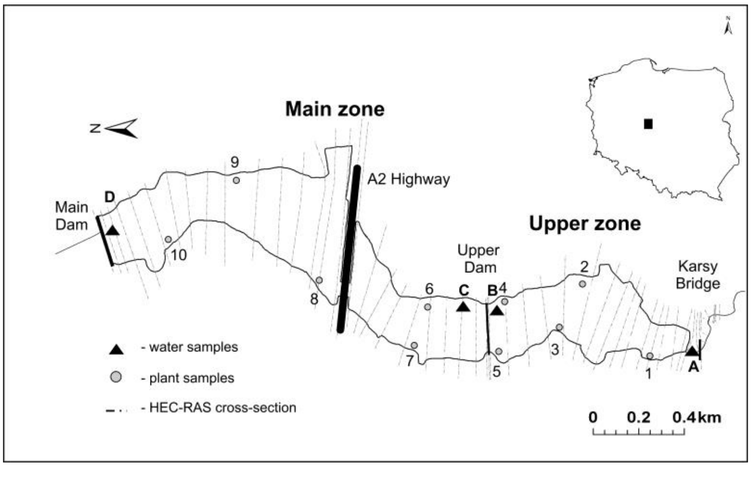

FIGURE 1
Study site location

The area of the upper part is 27 ha and the capacity of this part is 0.294×10^6 m^3. The upper part of the reservoir plays a specific role [3, 8]. It is used to protect the main reservoir against sediment and water quality degradation - the sediment particles transported with inflowing water are settled in the upper part of the reservoir [2].

The mean annual discharge of the Powa River amounts to 1.16 $m^3 \cdot s^{-1}$, the winter and summer half-year mean discharges are 1.71 $m^3 \cdot s^{-1}$ and 0,61 $m^3 \cdot s^{-1}$ respectively. The flow variability in 1975-2009 was very high, from 0.012 to 42.6 $m^3 \cdot s^{-1}$ (Fig. 2). The water management of the Stare Miasto reservoir shifts the time of high and low flow occurrences. In some years it changed the time of the yearly maximum and minimum flow events even up to half a year.

MATERIALS AND METHODS

The investigation was divided into three stages: (i) botanical survey focused on development of various vegetation types, (ii) habitat assessment focused on river hydraulics, hydrology, water quality and bottom sediments, (iii) search for relationships between developing vegetation and habitat conditions of the reservoirs with a separated upper zone.

Botanical survey was carried out in the year 2013 according to the Polish macrophyte monitoring method ESMI (Ecological State Macrophyte Index) compliant with the Water Framework Directive (2000/60/EC) for assessment of the ecological status of lakes [25]. The method relies on recording significant patches (areas of homogenous and uniform vegetation) taking into consideration both emergent and submerged plants. Observations of aquatic vegetation were performed along 30-m-wide belt transects, set perpendicular to the shoreline. The length of transects covered the entire vegetated area from the bank shore to the outer limit of macrophyte growth. Therefore all macrophytes growing in the reservoir are recorded, including submerged, floating and emergent plants (at least rooted in the water). The distribution of ten transects (five in each part of the reservoir) is illustrated in Fig. 1. Macrophyte abundance estimates were made using a seven point abundance scale [25].

The botanical survey allowed us to estimate qualitative and quantitative share of the main types of vegetation in the reservoir. On the basis of the records we could calculate several botanical metrics such as [3]: total vegetated area (N), colonisation index (Z) reflecting macrophyte abundance, Shanon diversity index H [26] and maximum diversity index H_{max}. Moreover, on the basis of the macrophyte survey, the Ecological State Macrophyte Index was calculated according to the following formula [3]:

$$ESMI = 1 - \exp\left[-J \times Z \times \exp\left(\frac{N}{P}\right)\right]$$

where J is the evenness of vegetation types (Pielou’s index of evenness) [27], Z is the colonisation index, N is the total area covered with vegetation and P is the lake area. Diversity metrics were calculated on the basis of the share of all communities in the transect.

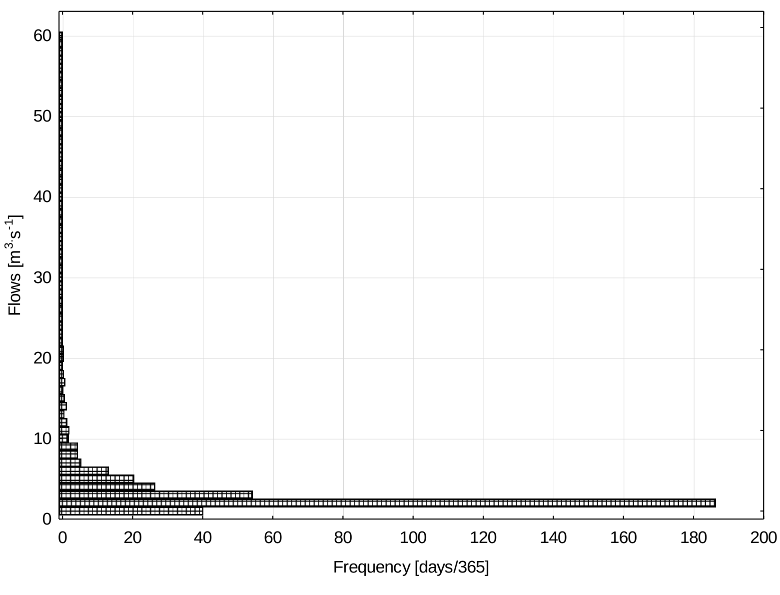

FIGURE 2
Discharge frequency curve for the gauge station Posoka on the Powa river, for the period 1971-2009

To estimate the reservoir morphology, the digital elevation model (DEM) of the Powa valley was completed. The DEM model was based on the topographic maps in the scales 1:2000 and 1:10000 made in the 1990s and other documents prepared for the reservoir construction. ArcGIS 9.3.1 by ESRI was used for DEM preparation. DEM permitted determination of changes in the morphological conditions after the Stare Miasto reservoir construction. Moreover, DEM allowed a correlation of the depth of the bottom and the recorded types of vegetation.

In order to assess the impact of variations in the hydraulic and hydrological parameters on the directions and speed of succession, the simulations of water surface profiles were made by means of HEC-RAS 5.0 Beta. The data used for the analyses included: (1) DEMs of the Powa river and the river valley, (2) discharges observed in the Posoka gauge station, (3) water stages observed in the headwater at the Stare Miasto dam. The analysis of the Powa river models combined with water stage observations permitted reconstruction of two stages of the character of the Powa river flow; the first was observed before the reservoir was built, the second - after it was built.

The simulations by means of HEC-RAS were made in a few steps. At first, the water surface profiles and hydraulic parameters for each discharge Q_i in the frequency curves (Fig. 2) were determined. The hydraulic parameters such as water velocity, depth of the reservoir and of the river, etc., were determined for each cross-section. The fundamental hydraulic parameters were water surface elevations in each cross-section. The frequency of related discharge was assigned to water surface elevation. This procedure enabled a construction of water stages frequency curves for each cross-section. Then the water stages frequencies were recalculated into the frequencies of inundation to a particular level, e.g. the level of vegetation occurrence.

In the next step the assessment of sediment deposition was undertaken. The grain size in bed sediments was determined. In 2011 and 2012, samples of sediments including (1) 5 samples from upper zone, (2) 5 samples from main zone, were collected. The selected sites were located in the transects used for vegetation identification. The positions of the survey sites are presented in fig. 1. The samples granulation was determined as a combination of sieve and aerometer analysis, according to Polish Norm PN-R-04032:1998 "Soils and minerals - Samples and analysis of granulation". The sieve analysis was made in the wet conditions with normalized set of sieves. The aerometric analysis was performed with a set of aerometric devices produced by Eijkelkamp company. According to the above-mentioned Polish Norm, the soil fractions taken into account were as follows: sand (2-0.05 mm), silt (0.05-0.002 mm) and clay (0.002 mm). The spatial distribution of sediments deposited in the reservoir was analysed taking into regard the types of soil classified before construction of the reservoir. The types of soils in the valley of the Powa river were determined on the basis of the soil map in the scale 1:25000. The Stare Miasto reservoir is built in the natural river valley. In the majority of the current reservoir area no earthworks aimed at modification of the ground surface were performed. Only the vegetation growing in the inundated area had been removed before the reservoir was built. In the inlet part of the reservoir (initial reservoir) the valley was deepened, because the original soil was removed. On the east and west banks of the reservoir the earthworks consisted of formation of the slopes.

The physical and chemical properties of water in the reservoir were determined for the samples collected in 2011 and 2012. The samples were taken every month at four sites: two in the upper zone and two in the main zone (Fig. 1). The water samples were taken from the subsurface layer with the help of a Ruttner's water sampler. The distributions of four water parameters measured at each site were determined. This set of parameters includes the contents of nutrients (ammonia, nitrates, nitrite and phosphates). The chemical analyses were performed in the laboratory at the Poznan University of Life Sciences. NH_4^+ was determined by the spectrophotometric method with Nessler's reagent; NO_2^-, with sulphanilic acid and 1-naphthylamine; NO_3^-, by the salicylate method; and PO_4^{3-} was determined by the molybdate method with ascorbic acid as a reducer, using a Merck Nova 60 apparatus (Merck KGaA, Germany).

To estimate the impact of different abiotic parameters on vegetation development several multivariate statistical methods were used. These were cluster analysis (CA), principal component analysis (PCA) and canonical correspondence analysis (CCA). The statistical analysis was made using the software Statistics 10 (StatSoft Inc.) and Canoco 4.5 (Biometris Plant Research International, Wageningen) (2011). The CA was performed on the basis of the Ward's method in order to illustrate similarities and differences between transects. The PCA method was used to explore the distribution of abiotic factors in the reservoir. The CCA was made in order to correlate the abiotic parameters with plant species distribution. The relationship between plant species and abiotic parameters was evaluated on the basis of the following parameters: transect location in the reservoir (TL), share of clay fraction in sediments (ClF), silt fraction (SiF) and sand fraction (SaF), average depth in the transect (TD), distance between the transect and to the former Powa channel (DfPC) and distance from the inlet of the

TABLE 1
Vegetation diversification in the Stare Miasto

Types of vegetation	Upper zone					Main zone					Dominating form*
	1	2	3	4	5	6	7	8	9	10	
Sparganietum erecti	2	4	2	3							Em
Sagittario-Sparganietum			5	1							Subm, Float, Em
Scirpetum maritimi					2						Em
Comm. Myosotis scorpioides			1	r							Em
Cariacetum acutae	+										Em
Potametum crispi	+	+		+							Subm
Hydrocharitetum morsus-ranae			r								Float
Glycerietum maximae	2				4			1			Em
Potametum pectinati		1			+				+	+	Subm
Iridetum pseudacori				r			+				Em
Lemnetum minoris	+						+				Float
Polygonetum amphibium	3			3						r	Float
Najadetum marinae	2	+		+	2	1	+	+	2		Subm
Typhetum latifoliae	+	1	+		2		+	1	2	3	Em
Phragmitetum australis	+	1	1			4	4	5	2	+	Em
Eleocharitetum palustris				1			1			1	Em
Phalaridetum arundinaceae				+	1	3	1	+			Em
Cariacetum ripariae						+	1	+			Em
Typhetum angustifoliae									3	4	Em
Number of communities	9	6	6	9	6	4	8	6	5	6	

*Dominating form: Subm – submarged, Float – floating leaves, Em - Emerged

Powa river to the reservoir (DfI), type of construction work done in the reservoir (CW) and frequency of inundations (FoI). In the study the earthworks are classified as follows: lack of earthworks - value 0.1, formation of slopes 0.5, deepening and removal of soils 0.9

RESULTS

Results of the botanical survey revealed the abundant development of macrophyte vegetation in the Stare Miasto reservoir. Nineteen different vegetation communities were identified (Table 1). Both, submerged and emergent macrophyte vegetation was recorded.

Different directions of vegetation development were identified in different parts of the reservoir. More diverse and abundant vegetation was found in the upper zone (Fig. 1), in which 16 vegetation types were identified (Table 1). Seven of them were absent in the rest of the reservoir. Especially large
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contribution in coverage was recorded for *Sparganietum erecti*, *Sagittario-Sparganietum emersi*, *Najadetum marinae* and *Polygonetum amphibium*. The Shannon diversity H was 1.72 and H_{max} was 2.77 (Table 2).

The main part of the reservoir located downstream was characterized by lower contribution of vegetation cover and lower diversity. In this zone only 12 plant communities were identified (Table 1) and only two of them were not observed in the rest of the reservoir. Especially large contribution in coverage was brought by *Phragmitetum australis*, *Typhetum angustifoliae* and *Phalaridetum arundinaceae*. The Shannon diversity H was 1.46 and H_{max} was 2.48 (Table 2).

The ESMI index was used to assess ecological potential of the Stare Miasto reservoir on the basis of macrophyte vegetation (Table 2). This index for the upper zone is slightly lower (ESMI=0.224) than that

TABLE 2
Evaluation of the ecological potential of the Stare Miasto reservoir on the basis of macrophytes development

Macrophyte assessment	Upper zone	Main zone
ESMI index	0.224	0.247
Ecological potential	moderate	moderate
Total vegetated area	7.2 ha	5.85 ha
Macrophyte abundance Z	0.31	0.44
Shanon diversity index H	1.72	1.46
Maximum diversity index H_{max}	2.77	2.48

characterising the part located near the dam (ESMI=0.247). In both investigated parts of the reservoir a similar level of degradation was observed, which permitted classification of the state of the reservoir as moderate.

The HEC-RAS simulations were used for the analysis of hydraulic and hydrological conditions in the valley of the Powa river before and after the reservoir was built. The results obtained are presented graphically in Fig. 3. The cross-sections are characterised by the frequency curves made for the water states before and after the reservoir was built. The curves were determined for a few scenarios of water conditions, taking into account the specific features of the reservoir and the river as well as the discharge variation in the reservoir inlet.

Before the reservoir was built, the valley of the Powa river was used as grassland or arable land. As shown in Fig. 3a and 3d, the appearance of the reservoir significantly changed the water conditions in this land. The valley was inundated and water level in the reservoir was regulated. It influenced deeply the vegetation conditions. The vegetation typical of reservoirs covered the inundated area. Specific construction of the reservoir (upper and main zones) and regular water management (filling and emptying) are the reasons for water vegetation diversity. In the upper zone (Fig. 1a), the water level is kept at 93.5 m a.s.l. (Fig. 3a). In the main zone the water level varies between 92.0 and

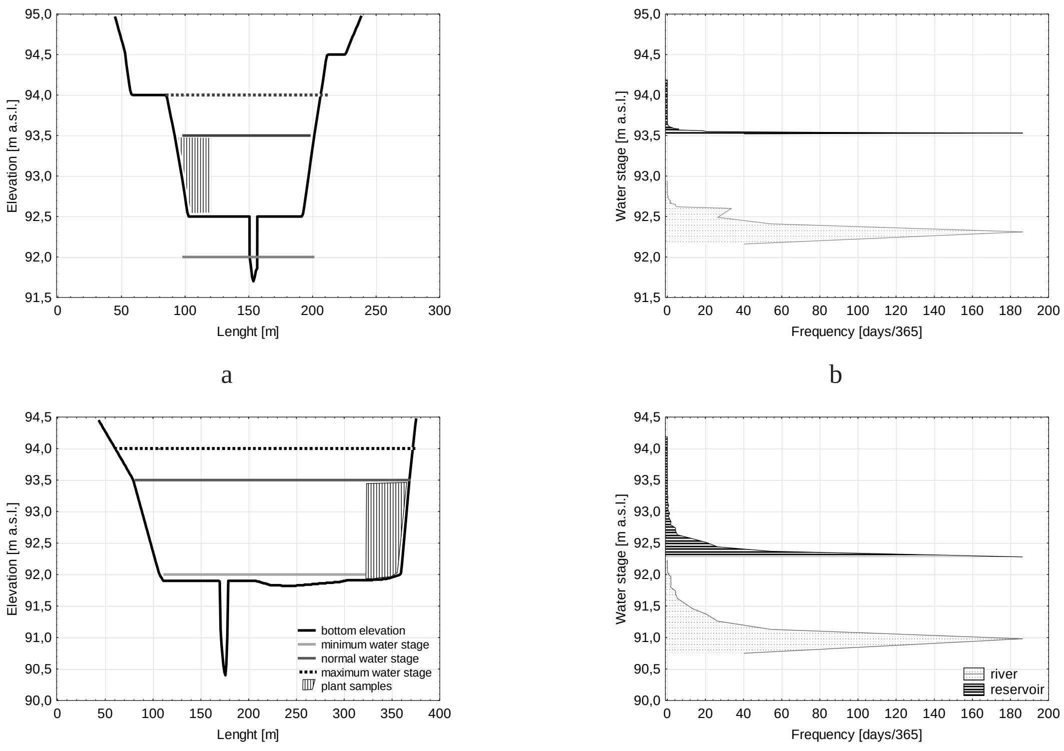

FIGURE 3
Cross-section of the Stare Miasto reservoir (a) and water stage frequency curve (b) for measurement site no. 1 and 6 respectively

TABLE 3
Comparison of inundation frequency in the river with that for the reservoir

Vegetation points	Elevation where vegetation point is located	Inundation frequency (days/365)	
		reservoir	river
1	93.25	365	0
2	93.5	365	0
3	92.5	365	0.1
4	92.24	365	1.3
5	93.69	0.2	0
6	92.66	19	0
7	93.5	0.7	0
8	91.87	365	0
9	92.92	5.4	0
10	90.78	365	0.5

94.0 m a.s.l. (Fig. 3d). More stable conditions in the upper zone (constant water level, relatively smaller changes in the water stages) and lower depth lead to higher diversity of vegetation as well as higher plants abundance. Table 3 lists the earlier presented bottom elevations and inundations. These are the lowest elevations, at which the plants observed in 2013 grew. On the basis of simulations the number of days on which this level is submerged can be assessed. In selected 10 sites the number of such days varies from one day to the whole year. As far as the river without floodplains is concerned, site no. 4 is inundated for two days. The other sites are fully above the water all the year (Table 3).

At the next stage, the grain size of bottom sediment samples were analysed. The results obtained showed that the sediment grain sizes in particular zones of the reservoir differ significantly. In the inlet part of the upper zone, where the flow velocities reach the highest values, coarse sediments are deposited. The total amount of sand fraction in the samples from this part is close to 95%. In the central and downstream parts of the upper zone, the bottom sediments may be characterized as loamy-sands and sandy loams. In these parts of the reservoir, there are the best conditions for deposition of fine fractions. The total amount of silt plus clay in the samples from these parts ranges from 16 to 42 % (Table 4). In the main zone the sediments are coarser. There are mainly sands with little amount of silt and clay. The total amount of sand fraction in the samples from the main zone varies from 87 to 91%. Only in the sediment sample 8 located downstream the highway, the total amount of silt and clay is only 1%. Below the highway the culvert width only 25 m that caused increase in water velocity and removal of finer fractions.

Analysis of the nutrient content also confirmed differences between the upper and lower zones of the reservoir. In the upper zone the concentrations of nutrients in the upstream and downstream parts were similarly low. As far as nitrogen forms are concerned, the concentrations of nitrates was relatively high, whereas the concentration of ammonia was low (Table 5). The amount of phosphates in water was also low, with the average value of 0.06 mg dm^{-3}. In the main zone the average and maximum concentrations of nitrates were lower than in

TABLE 4
Grain sizes of bottom sediments in the Stare Miasto reservoir

Parameter	Upper zone				Main zone					
	1	2	3	4	5	6	7	8	9	10
Type of sediments	*Sa*	*LoSa*	*SaLo*	*SaLo*	*SaLo*	*Sa*	*Sa*	*Sa*	*Sa*	*Sa*
Sand [%]	95	58	77	80	84	88	91	99	91	87
Silt [%]	3	39	21	19	15	9	5	0	6	5
Clay [%]	2	3	2	1	1	3	4	1	3	8
d_{10} [mm]	0.065	0.011	0.013	0.018	0.017	0.043	0.055	0.063	0.052	0.009
d_{50} [mm]	0.160	0.094	0.145	0.149	0.161	0.150	0.177	0.151	0.139	0.096
d_{90} [mm]	0.243	0.712	0.402	0.248	0.334	0.356	0.394	0.433	0.241	0.417

TABLE 5
Concentrations of nutrients in the water of the Stare Miasto reservoir

Parameters	Upper zone		Main zone	
	A	B	C	D
Nitrates NO_3 [mg·dm^{-3}]	5.21-3.54 0.01-19.49	5.21-3.10 0.01-23.04	4.30-3.99 0.01-11.08	4.88-3.10 0.01-13.29
Nitrite NO_2 [mg·dm^{-3}]	0.10-0.10 0.01-0.20	0.07-0.07 0.01-0.16	0.08-0.07 0.01-0.16	0.08-0.03 0.01-0.23
Ammonia NH_4 [mg·dm^{-3}]	0.04-0.01 0.01-0.17	0.04-0.01 0.01-0.29	0.02-0.01 0.01-0.08	0.06-0.01 0.01-0.63
Phosphates PO_4 [mg·dm^{-3}]	0.06-0.06 0.01-0.17	0.05-0.02 0.01-0.22	0.05-0.01 0.01-0.20	0.04-0.01 0.01-0.20

*mean-median
min-max

the upper zone. The same tendency was observed in the concentrations of phosphates. The statistical significance of differences between average concentrations of nitrogen and phosphorus compounds was evaluated. The assessment was performed by means of t-Student test for independent samples with 95% level of confidence. The results showed no significant differences between the mean concentrations of nitrogen and phosphorus compounds in the upper and main zones.

To identify abiotic parameters influencing the vegetation development the cluster analysis was undertaken. It revealed that the transects can be divided into two groups (Fig. 4). The first group included transects from the upper zone (Group I). These two transects were located close to the Powa inlet (transects 1 and 2) which was the shallowest part of the reservoir where extensive deepening and organic matter removal were applied. The other transects from the upper zone were situated in the area of homogenous sediment granulometry. In this part the best conditions for deposition of fine fractions took place. The total concentration of silt and clay ranges from 16 to 23%.

In the main zone of the reservoir the set of abiotic conditions was identified as a separate main cluster (Group II). Transects 6, 8 and 10 were situated at the deepest part of reservoir (between 1.5 to 1.7 meters). Transects 7 and 9 were delimited in the zone of lower depth (less than 0.6 meter). The sediments were dominated by sand (91%) and the rest of loam and silt made a contribution of 9%.

The principal component analysis allowed distinction of the three main directions of variability on the basis of nine parameters describing the abiotic environment (fig. 5 a-b). The main components explained 84% of internal data structure. The first main component was correlated with: the frequency of inundation (FoI), location of transect in the reservoir (TL), the distance from the reservoir inlet (DfI) and fraction of sand (SaF) and silt (SiF) in the bottom sediments. The relationships between these elements indicated the existence of hydrologic gradient (water stage and sediment transport). In the reservoir there are permanently inundated parts whose bottom sediments are dominated by silt fraction. On the other hand, there are also zones in the main reservoir, where inundation is only temporal and their bottom sediments are dominated by sands.

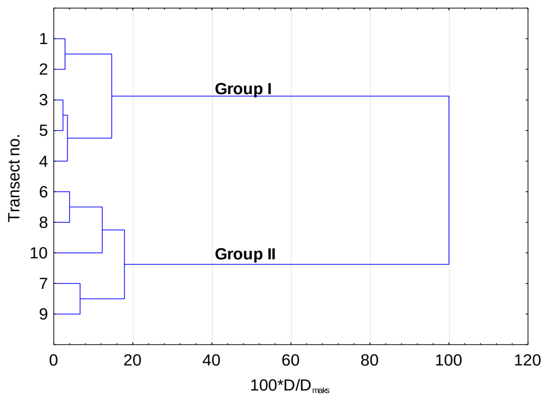

FIGURE 4
The analysis of similarity of abiotic parameters

The factor indicated by the second main PCA factor was most strongly correlated with the distance between the transect and the old channel of the Powa river (DfPC). This factor was associated with the water management pattern. The transects, positively associated with this factor were strongly affected by high dynamics of water level fluctuations resulting from the reservoir water management. The second PCA component was also partly associated with the type of construction works (CW) but this factor was more important for the third PCA component.

The third main component was strongly correlated to the type of construction works (CW) (Fig. 5b). The transects, positively correlated to this component, were affected by intensive construction works. The engineering efforts included deepening of the floodplains and shaping of the banks. All

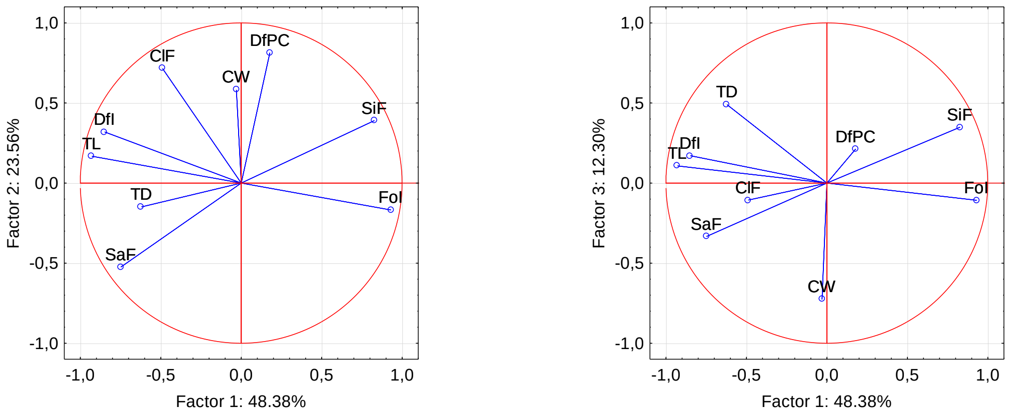

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FIGURE 5
The principal component analysis in relation to abiotic parameters

environmental variables indicated significant dependence on extracted main components with exception of clay fraction in bottom sediments (ClF) and depth (TD).

In order to estimate the impact of abiotic factors on the growth and distribution of macrophytes in the Stare Miasto reservoir, the canonical correspondence analysis (CCA) was made (Fig. 6.). The CCA results indicated that the first two directions of variability extracted by PCA, strongly influenced the vegetation diversity in the reservoir. Both factors showed comparable impacts on macrophyte differentiation. The third PCA factor seems to have minor importance in relation to riparian vegetation differentiation.

The first PCA component, linked with hydrological factors (water stage and sediment transport) was strongly correlated to the growth of *Sparganietum erecti*. The positive dependence on this factor was observed for several submerged macrophytes (*Potametum crispi, Potametum pectinati)* and unrooted free-floating (*Hydrocharis morsus-ranae)*. These groups of macrophytes require longer periods of inundation. The negative dependence to the second PCA factor was observed only for several groups of emergent plants, especially *Typhetum latifoliae* and *Typhetum angustifoliae*. These plants grow well in temporally inundated areas.

The second PCA component was also linked to *Typhetum latifoliae* and *Typhetum angustifoliae*). Patches of *Potametum pectinati* showed strong relationship with both, the first and the second components of PCA.

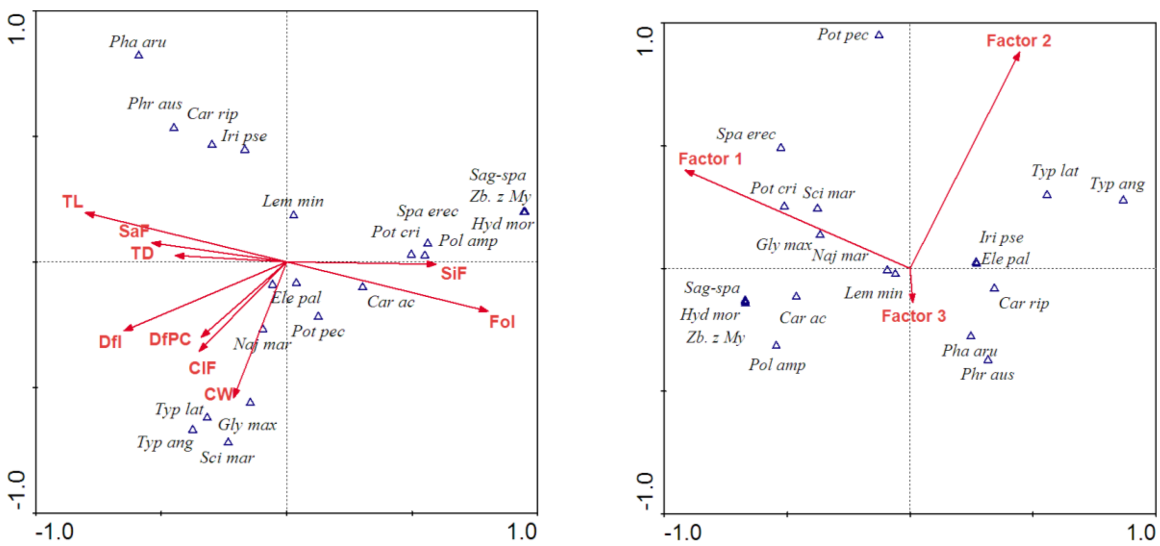

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FIGURE 6
Canonical correspondence analysis for aquatic vegetation of the Stare Miasto reservoir

DISCUSSION

The retention reservoir studied is currently at the first stage of its functioning and the processes taking place in it are similar to those observed for other reservoirs of this type. At the first stage of functioning of such reservoirs, the plant communities characteristic of rivers and land of the area are destroyed and gradually replaced by those characteristic of lakes [28].

The reservoirs of this type have been rarely analysed [29, 30]. This is the pioneering analysis of the impact of hydrological, hydraulic, physical and chemical factors as well as sediment deposition in the reservoir on rate and direction of the plant succession. Changes in hydrological and hydraulic conditions together with changes in sediment transport intensity in the analysed area cause dynamic changes in the habitat conditions. Small depths in the upper zone of the reservoir and huge sediment load are responsible for the higher dynamics of succession there than that of the processes taking place in the main part.

Plant response to the habitat condition was very evident. The vegetation was much differentiated, the presence of 19 types of vegetation proves that the plant succession was very advanced. This number of different plant communities is comparable to that in natural lakes [25]. We have revealed that the succession of aquatic plants in the artificial reservoirs goes very fast and the vegetation differentiation is comparable to that in natural lakes.

The degradation of the water quality in the investigated reservoir is moderate. The observed level of biogenic compounds is low in comparison with other lowland reservoirs [28]. The water quality in the reservoir is even better than typical observed in the natural lowland lakes [9, 31, 32].

The computations of the reservoir performance time in the aspect of limitation by sedimentation [33] indicate at least 80 years of its undisturbed functionality. The necessity of sediment removal from the upper zone after 9 years of the reservoir existence shows the huge dynamics of the processes taking place in the inlet area.

CONCLUSIONS

1. Construction of the reservoir resulted in deep changes of hydraulic and hydrological pattern as well as physical and chemical conditions in the valley of the Powa river, influencing the development of new vegetation.

2. Aquatic plant succession in the artificial reservoirs goes very fast and the vegetation differentiation has reached a level similar to that of natural lakes.

3. The constant water level, smaller depth and greater inflow of sediments in the upper zone of the reservoir stimulated abundant vegetation growth and greater species diversity.

4. Vegetation development in the reservoir is influenced most strongly by hydrological factors (water level and sediment transport) and the reservoir management pattern.

REFERENCES

[1] Banasik K., Gorski D., Popek Z. and Hejduk L. (2012) Estimating the annual sediment yield of a small agricultural catchment in central Poland. IAHS-AISH publication, 267–275.

[2] Dysarz T. and Wicher-Dysarz J. (2011) Application of hydrodynamic simulation and frequency analysis for assessment of sediment deposition and vegetation impacts on floodplain inundation. Polish Journal of Environmental Studies 20(6), 1441-1451.

[3] Dysarz T. and Wicher-Dysarz J. (2013) Analysis of flow conditions in the Stare Miasto reservoir taking into account sediment settling properties. Annual Set The Environment Protection 15(1), 584-605.

[4] Dąbkowski Sz.L, Skibiński A. and Żbikowski A. (1982) Hydraulic principles of water reclamation projects. (In Polish) PWRiL Warszawa.

[5] Łajczak A. (1995) A study on siltation of selected dam reservoirs in the Vistula catchment basin (in Polish). KGW 8 PAN Warsaw.

[6] New T. and Xie Z.Q. (2008) Impacts of large dams on riparian vegetation: applying global experience to the case of China's Three Gorges Dam. Biodivers. Conserv. 17(13), 3149-3163.

[7] Chen, S.Q., Chen, B. and Su, M.R. (2011) An estimation of ecological risk after dam construction in LRGR, China: Changes on heavy metal pollution and plant distribution. (International Congress on Environmental Modelling and Software Modelling for Environment's Sake (iEMSs2010), Fifth Biennial Meeting, Ottawa, Canada). Procedia Environmental Sciences 5, 153-159.

[8] Sojka M., Siepak M., and Gnojska E. (2013) Assessment of heavy metal concentration in bottom sediments of Stare Miasto pre-dam reservoir on the Powa River (in Polish). Annual Set The Environment Protection 15(2), 1916-1928.

[9] Sojka M., Kanclerz J., Dysarz T., Wicher-Dysarz J. (2015). Application of mulitivariate statistical methods for analysis of physical and chemical factors in reservoir with separated

pre-dam zone on the basis of the Jezioro Kowalskie example. Frasenius Environmental Bulletin Vo. 24- No.4b 1516-1522

[10] Wiatkowski M. (2011) Influence of Słup dam reservoir on flow and quality of water in the Nysa Szalona river. Polish Journal of Environmental Studies 20(2), 467-476.

[11] Kellogg C. H. and Zhou X. (2014) Impact of the construction of a large dam on riparian vegetation cover at different elevation zones as observed from remotely sensed data. International Journal of Applied Earth Observation and Geoinformation 32, 19-34.

[12] Tealdi S., Camporeale C. and Ridolfi, L. (2011) Modeling the impact of river damming on riparian vegetation. Journal of Hydrology 396(3), 302-312.

[13] Traczewska, T. M. (2012) Ecological problems of reservoirs in the aspect of their multifunctionality. Politechnika Wrocławska, Instytut Inżynierii Środowiska (in Polish).

[14] Li J., Dong S., Yang Z., Peng M., Liu S. and Li X. (2012) Effects of cascade hydropower dams on the structure and distribution of riparian and upland vegetation along the middle-lower Lancang-Mekong River. Forest Ecology and Management 284, 251-259.

[15] Mallik A.U. and Richardson J.S. (2009) Riparian vegetation change in upstream and downstream reaches of three temperate rivers dammed for hydroelectric generation in British Columbia, Canada. Ecological Engineering 35(5), 810-819.

[16] Nilsson C. and Svedmark M. (2002) Basic principles and ecological consequence of changing water regimes: riparian plant communities. Environmental Management 30, 468-480.

[17] Rood S.B., Braatne J.H. and Goater L.A. (2010) Favorable fragmentation: river reservoirs can impede downstream expansion of riparian weeds. Ecol. Appl. 20, 1664-1677.

[18] Xiaoyan L., Shikui D., Qinghe Z. and Shiliang L. (2010) Impacts of Manwan Dam construction on aquatic habitat and community in Middle Reach of Lancang River. Procedia Environmental Sciences 2, 706-712.

[19] Gurnell A.M. and Petts G.E. (2002) Island-dominated landscapes of large floodplain rivers, a European perspective. Freshwater Biol. 47(4), 581-600.

[20] James W.F., Best E.P. and Barko, J.W. (2004) Sediment resuspension and light attenuation in Peoria Lake: can macrophytes improve water quality in this shallow system? Hydrobiologia 515, 193-201.

[21] Szoszkiewicz K., Ciecierska H., Kolada A., Schneider S. C., Szwabińska M. and Ruszczyńska J. (2014). Parameters structuring macrophyte communities in rivers and lakes – results from a case study in North-Central Poland. Knowl. Management. Aquatic Ecosyst. 415, 08.

[22] Van Geest G.J., Roozen F.C.J.M., Coops H., Roijackers R.M.M., Buijse A.D., Peeters E.T.H.M. and Scheffer M. (2003) Vegetation abundance in lowland flood plain lakes determined by surface area, age and connectivity. Freshw. Biol. 48, 440-454.

[23] Krolová M., Čížková H. and Hejzlar J. (2012) Depth limit of littoral vegetation in a storage reservoir: A case study of Lipno Reservoir (Czech Republic). Limnologica-Ecology and Management of Inland Waters 42(2), 165-174.

[24] Krolová M., Cížková H., Hejzlar J. Poláková S. (2013) Response of littoral macrophytes to water level fluctuations in a storage reservoir Knowledge and Management of Aquatic Ecosystems 408, 07.

[25] Ciecierska H. and Kolada A. (2014) ESMI: a macrophyte index for assessing the ecological status of lakes. Environmental Monitoring and Assessment 186(9), 5501-5517.

[26] Shannon C.E. and Weaver W. (1949) The mathematical theory of communication. University of Illinois Press, Urbana.

[27] Pielou E.C. (1975) Ecological diversity. Wiley New York.

[28] Wiatkowski M., Rosik-Dulewska C., Kuczewski K. and Kasperek R. (2014) Water quality assessment of Włodzienin reservoir in the first year of its operation (in Polish). Annual Set The Environment Protection 15(3), 2666-2682.

[29] Kasperek R. and Wiatkowski M. (2008) Research on bottom sediments from the Msciwojow reservoir (in Polish). Przegląd Naukowy Inżynieria i Kształtowanie Środowiska, 40, 194–201.

[30] Pikul K. and Mokwa M. (2008) Influence of pre-dam reservoir on sedimentation process in main reservoir, Przegląd Naukowy Inżynieria i Kształtowanie Środowiska 40, 185-193.

[31] Przybyła Cz., Zbierska A. and Dwornikowska Ż. (2011) Assessment of Water Quality Changes in Selected Lakes of Poznań Lakeland in 2004-2009 (in Polish). Annual Set The Environment Protection T. 13, 723-746.

[32] Sojka M., Siepak M., Zioła A., Frankowski M., Murat-Błażejewska S. and Siepak J. (2008) Application of multivariate statistical techniques to evaluation of water quality in the Mała Wełna River (Western Poland). Environmental monitoring and assessment, 147(1-3), 159-170.

[33] Wicher-Dysarz J. and Dysarz T. (2015) Uncertainty in assessment of annual inflow of sediments to the Stare Miasto reservoir based on empirical formulae. Acta Sci. Pol., Formatio Circumiectus 14(1) (in Polish).

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