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Original Research

Ecological Classification of Artificial Reservoirs in Polish Lowlands According to Water Framework Directive Requirements

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Abstract

With the adoption of the Water Framework Directive, monitoring of surface waters has undergone a reform process. It introduced a new approach to the assessment of surface waters based on biological elements. In the case of water reservoirs, the monitoring is based on phytoplankton, phytobenthos, and macrozoobenthos, as well as chlorophyll concentrations. The ecological evaluation is supported by physical-chemical and hydromorphological characteristics. The study was based on national monitoring data coming from 10 reservoirs in the lowland landscape. Our analysis revealed that the classification of reservoirs was determined both by physical-chemical and biological factors. It was found that good and better than good ecological potential was achieved by three reservoirs, while three more were classified as moderate and four as bad. Principal component analysis showed that the biological elements are strongly associated with the level of phosphorus in the water. The ecological potential of the reservoirs does not depend on the surface area or depth of the water body, nor it is related to water retention time.

Keywords: Water Framework Directive, water monitoring, ecological potential, dam reservoir

Introduction

Reservoirs are man-made water bodies usually formed by building a dam across a river valley. For centuries they have played an important role supporting economic and social development, and delivering important services such as power generation, flood control, and increasing and balancing the water supply for irrigation and other purposes such as water retention [1]. The other advantages of the construction of dam reservoirs are fishery management and recreational opportunities [2-3].

For a few decades, dam construction has often been viewed from a critical angle. It is highlighted that the water above the dam loses its lotic nature in favor of

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lenitic conditions [4]. The consequences are deep changes in hydrological and ecological processes, for example: fish migration obstacles, riverbed erosion (downstream of dams), rising water temperatures, increasing sedimentation, and rising water exchange periods [5-7], as well as habitat deterioration for many species [8-9]. Moreover, reservoir construction causes various negative changes in water quality, such as eutrophication, oxygen deficits, and water transparency change [9]. They have larger inputs of nutrients and greater water-level fluctuations than natural lakes, escalating the eutrophication effect [10-11].

The assessment and monitoring of the surface waters in EU countries is conducted in accordance to the requirements of the EU Water Framework Directive (WFD) [12], which is based mainly on biological methods. The physical-chemical and hydromorphological quality factors are all supporting factors for biological evaluation. The monitoring water quality is carried out for surface waters, which include rivers, lakes, and transitional waters, as well as coastal waters. For natural waterbodies such as lakes and rivers, biological elements enable us to determine ecological status. In the case of heavily modified or artificial water bodies such as dam reservoirs, the so-called ecological potential is estimated [13].

According to the requirements of the WFD, the dam reservoir assessment has been implemented for several years and various problems have already been revealed. They refer to aspects such as the lack of reference conditions [11] or the overall habitat heterogeneity of the reservoir [14]. Moreover, the evaluation of artificial reservoirs will always be complex, since their ecological properties are intermediate between lakes and rivers but different from both [11]. It should also be noted that water reservoirs are particularly vulnerable to nutrients, and the eutrophication effect is escalated and strongly shifting in their biological communities [10-11]. The very large scale of eutrophication in Poland [15-16] is causing a distinct reaction by many groups of organisms [17-19]. Recent results of reservoir monitoring should be analysed and utilised for the improvement of the existing methods, and Polish examples can be very helpful since the scale of degradation is very high.

The main aim of our study was to differentiate biological as well as physical-chemical and hydromorphological indicators of dam reservoirs, and to draw attention to the parameters determining their classification. We analyzed the monitoring data coming from reservoirs in the lowland regions of Poland.

Material and Methods

The research results were analyzed in terms of ecological potential assessment and the states of 10 water reservoirs. The following criteria were chosen in the selection of reservoirs for analysis:

- Location: different parts of Polish lowlands (Fig. 1).
- Differentiation of reservoir surface areas: small, medium, large.
- Differentiating reservoir depth: deep (stratified) and shallow (non-stratified).

Wloclawek was the largest reservoir among the analyzed ones (7,040 ha) while the smallest was Rzeszow (54 ha) [3].

Table 1 shows a list of reservoirs with the essential information.

Table 1. List of analyzed reservoirs and their characteristics.

Lp.	Reservoir	District	Date of studies	Maximum surface area [ha]	Maximum depth [m]	Average depth [m]	Type of reservoir	Type of water body
1	Wloclawek	Kuyavian-Pomeranian Province	2012	7040	15.0	4.9	R	artificial
2	Jeziorsko	Lodź Province	2011	4230	11.0	4.5	L	strongly modified
3	Siemianowka	Podlaskie Province	2012	3250	7.0	2.4	L	strongly modified
4	Sulejow	Lodź Province	2011	2380	11.3	3.3	T	strongly modified
5	Koronowo	Kuyavian-Pomeranian Province	2012	1560	21.2	5.2	T	artificial
6	Nielisz	Lublin Province	2012	888	8.6	2.3	L	artificial
7	Slupca	Greater Poland Province	2012	260	4.1	2.5	L	strongly modified
8	Brody Ilzeckie	Holy Cross Province	2012	190	8.1	3.8	T	strongly modified
9	Bledzew	Lubusz Province	2012	80	6.5	3.3	R	artificial
10	Rzeszow	Subcarpathian Province	2012	54	6.5	2.5	R	strongly modified

Fig. 1. Locations of the analyzed reservoirs.

The biological components considered to evaluate the ecological potential of water reservoirs are phytoplankton organisms, benthic macroinvertebrates, and phytobenthos organisms [20]. The macrophytes are not applied in the assessment of the ecological potential of artificial aquatic ecosystems because of changes in water level, which cause poor growth of phyto-littoral. Furthermore, the assessment does not include fish fauna, because in reservoirs the fish usually form populations dominated by 2-3 species (especially by *Abramis brama* L. and *Rutilus rutilus* L., as well as in some cases by *Perca fluviatilis* L.) [20].

In addition to the biological elements, the ecological potential assessment is supplemented by a number of physical and chemical parameters such as oxygenation conditions, salinity, acidification, nutrients, and particularly harmful substances (the specific synthetic and non-synthetic pollutants). Moreover, several chemical parameters as priority substances and other pollutants are evaluated in the water [20].

We analyzed the monitoring results of 10 dam reservoirs where the standard monitoring methods were applied [20]. The following metrics were utilized in the analysis:

– "FLORA" bioindicators:
  - Phytoplankton: quantitative and qualitative analysis with the use of an inverted microscope and cylindrical sedimentation chambers.
  - Chlorophyll *a*: spectrophotometric measurement of the concentration in the water.
– Phytobenthos:
  - The diatoms: quantitative and qualitative analysis with the use of an optical microscope using the oil immersion objective.
– Macrozoobenthos
  - Benthic invertebrate fauna: quantitative and qualitative analysis using a stereoscopic microscope.

The physical-chemical parameters of water are based on samples collected during different parts of the year, at least three times annually. The following parameters were analyzed:

– Physical and aerobic conditions, salinity, acidification, nutrients
– Specific synthetic and non-synthetic pollutants
– Priority substances and other pollutants (in assessing the physical-chemical status)

The morphological conditions were estimated considering variation in the depth of the water body, the amount and structure of the reservoir bed, or structure and condition of the coastal zone corresponding to the undisturbed or nearly undisturbed conditions [20].

Comprehensive assessment of biological, physical-chemical, and hydromorphological parameters delivers the final evaluation of ecological potential of water reservoirs as defined by Polish national regulations [20]. The collected data were subjected to principal components analysis (PCA) in order to identify the main directions of the variability of water quality indicators, including the volume and depth of the reservoir. Statistical analyses were performed in Statistica software, v. 10.

Results and Discussion

The study showed differentiation of the degradation level between water reservoirs in terms of biological and physical-chemical parameters. Classification based

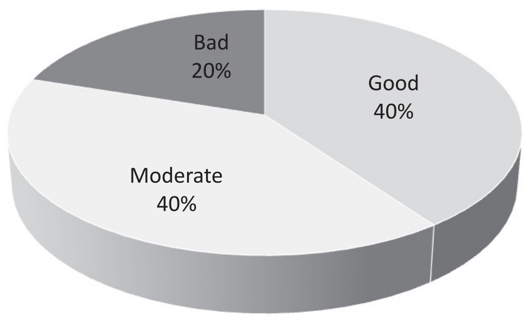

Fig. 2. Reservoir classifications based on biological parameters.

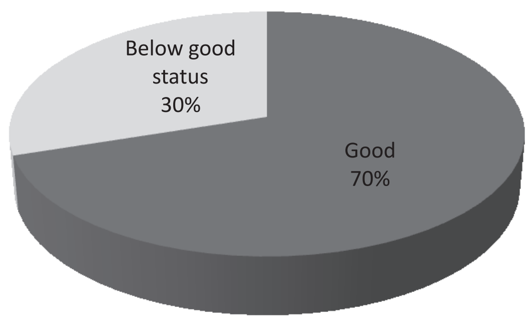

Fig. 3. Reservoir classifications based on physical and chemical parameters.

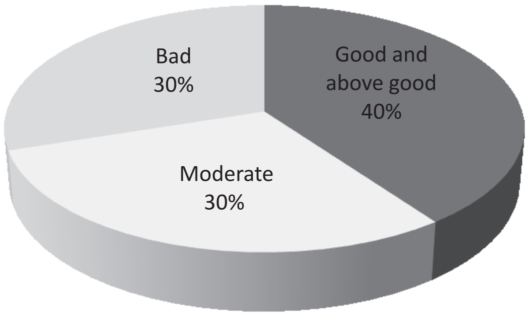

Fig. 4. Reservoir classifications according to ecological potential.

on biological parameters revealed that the ecological potential of four water reservoirs was at a good level (Fig. 2): Sulejow, Jeziorsko, Rzeszow, and Nielisz. The most degraded were Siemianowka and Slupca (bad ecological potential).

Classification based on physical and chemical parameters revealed that three of the analyzed water reservoirs achieved moderate ecological potential (Brody Ilzeckie, Siemianowka, and Slupca). Seven other reservoirs were classified as good, in terms of physical and chemical properties (Fig. 3). Among the analyzed parameters, the worst results were obtained for BOD_5, and this was the worst parameter in three reservoirs (Table 2). Other parameters reaching low values included total organic carbon content (TOC) as well as phosphates and total phosphorus concentrations (Table 3).

The final assessment of ecological potential, based on a multimetrix consisting of biological, physical-chemical, and hydromorphological parameters, showed that four reservoirs were classified as being in a good and above-good state (Fig. 4.): Sulejow, Jeziorsko, Rzeszow, and Nielisz. On the other hand, three reservoirs (Brody Ilzeckie, Siemianowka, and Slupca) showed bad ecological potential for their waters.

The analysis of principal components (PCA) allowed us to evaluate the variability of the main directions of the matrix with a wide range of parameters (Table 3). The first factor representing the main direction of change was associated with all biological indicators (phytoplankton and phytobenthos, as well as those associated with the flora index) and the overall class of biological elements. It was found that the first component was also associated

Table 2. Ecological potential of the uniform water bodies with the analyzed reservoirs.

No.	Reservoir name	Biological elements					Hydro-morphology	Physico-chemical components		Ecological potential
		Phytoplankton (Index IFPL)	Phytobenthos (IO)	Class of indicator FLORA	Benthic macroinvertebrates (MZB)	Class of biological elements	Class of hydromorphological elements	Decisive indicator of physico-chemical state	Class of physico-chemical elements	
1	Wloclawek	0.57	0.55	III	0.49	III	II	BOD_5, Formaldehyde, Volatile phenols, COD-Cr, Petroleum hydrocarbons (PHC)	II	Moderate
2	Jeziorsko	0.69	0.63	II	0.61	II	II	Cooper, Volatile phenols	II	Good and above good
3	Siemianowka	0.14	-	V	-	V	I	TOC	BGP	Bad
4	Sulejow	0.60	0.74	II	-	II	I	BOD_5, Kjeldahl nitrogen, Chromium VI, Volatile phenols, Free cyanide,	II	Good and above good
5	Koronowo	0.61	0.67	III	0.63	III	II	pH	II	Moderate
6	Nielisz	0.71	0.66	II	0.52	II	II	BOD_5, pH, Petroleum hydrocarbons (PHC)	II	Good and above good
7	Slupca	0.13	-	V	-	V	I	BOD_5, TOC, pH, Phosphates, Total phosphorus	BGP	Bad
8	Brody Ilzeckie	0.35	0.60	III	-	III	II	BOD_5	BGP	Bad
9	Bledzew	0.44	0.44	IV	0.63	III	I	TOC, Volatile phenols, Petroleum hydrocarbons (PHC)	II	Moderate
10	Rzeszow	0.78	0.56	II	0.58	II	II	Dissolved oxygen	II	Good and above good

Table 3. PCA principal component analysis for biological and abiotic parameters of analysed lowland reservoirs.

Parameters	Factor 1	Factor 2	Factor 3
Reservoir area	0.135	-0.687	0.331
Maximum depth	-0.232	-0.865	-0.088
Avarage deph	-0.120	-0.805	0.002
Phytoplankton	-0.875	-0.202	0.288
Phytobenthos	-0.874	-0.366	-0.131
Flora	0.932	0.112	-0.115
Class of biological quality	0.942	0.085	-0.123
Hydromorphology	-0.562	-0.384	0.387
Dissolved oxygen	0.568	0.196	-0.707
BOD_5	0.644	0.489	-0.210
Total organic carbon	0.815	0.428	-0.214
Electrolytic conductivity	0.005	-0.017	0.955
Nitrate nitrogen	-0.540	0.249	0.364
Total nitrogen	0.384	0.740	-0.066
Phosphates	0.635	0.617	0.069
Total phosphorus	0.777	0.471	0.107
Ecological potential	0.943	0.051	-0.055
Variance explained	7.426	3.887	2.053
Total share	43.7%	22.9%	12.1%

with several abiotic parameters, most strongly with TOC and total phosphorus in water.

The second direction of variability corresponded to the morphometric parameters, in particular to the maximum and average depths of the reservoir. The significant relationship of total nitrogen to the second main component also was detected. The third direction of change demonstrated association with water conductivity and dissolved oxygen level.

Analysis showed that based on the four biological parameters (phytoplankton, chlorophyll *a*, phytobenthos, macrozoobenthos), the comprehensive evaluation of the ecological potential of water reservoirs fulfilled meeting requirements set out by the WFD [12, 21]. Assessment of ecological potential is the first step of water body classification [22].

Performed analysis on the ecological potential of 10 representative water reservoirs in Polish lowlands showed that some of them can reach a satisfactory level of quality, according to WFD requirements. We have found that four of them have a good and above-good potential. This group of reservoirs is very variable in terms of the hydrometric conditions of water surface area, depth, and rate of water exchange. This group includes two very large reservoirs, Jeziorsko (4,230 ha) and Nielisz (888 ha), as well as the smallest of the analyzed water bodies, Rzeszow, with a surface area of only 54 ha. The reservoirs representing the highest ecological potential show the extreme range of typological diversity, since Rzeszow belongs to the rheolimnetic lakes, which have water retention lower than 20 days. Sulejow is a transition reservoir with an average retention time of 20-40 days. On the other hand, Jeziorsko and Nielisz are typical limnic reservoirs, with retention times of more than 40 days.

The analysis of principal components revealed that biological indicators are strongly associated with the level of total phosphorus in water. Phosphorus compounds belong to the main factors limiting primary production in aquatic ecosystems [10, 17-18, 22-23], thus they affect the secondary production rate [10, 16, 24-25]. Based on the performed analysis, it can be concluded that a reduction of the phosphorus level in water is the most important element mitigating the effects of the degradation of the studied reservoirs. The limitation in phosphorus input can significantly contribute to the improvement of the ecological potential of lowland water reservoirs in Poland as well as in other countries. The ecological potential of the reservoirs does not depend on the surface area or depth of the water body, nor it is related to water retention time.

Conclusion

1. The new system of monitoring following WFD requirements was widely introduced in Poland. The system is based on comprehensive assessment methods and allows for the classification of artificial water reservoirs.
2. Environmental assessment of lowland water reservoirs revealed differences in the degree of their degradation. It has been shown that 40% of studied reservoirs present satisfactory ecological potential, thereby meeting WFD requirements.
3. The degree of ecologically measured degradation of the reservoirs does not depend on the surface area and depth of the water body. Neither it is related to water retention time.
4. Among the analyzed physical-chemical parameters, the factors most strongly affecting the final reservoir classification were oxygen conditions (dissolved oxygen, BOD_5) and total organic carbon.
5. The biological metrics in reservoirs depends mostly on the concentration of phosphorus and organic carbon in water.

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