Carpathian Journal of Earth and Environmental Sciences, August 2018, Vol. 13, No. 2, p. 409 - 421; DOI:10.26471/cjees/2018/013/035

EUTROPHICATION RISK OF WATER IN THE MANOR-PARK CHANNELS: DIFFERENT WAYS OF EVALUATION

Łukasz BOREK[1]

[1]*Department of Land Reclamation and Environmental Development, University of Agriculture in Krakow, Al. Mickiewicza 24-28, Krakow, Poland, e-mail: l.borek@ur.krakow.pl*

Abstract. The problem of water eutrophication of the shallow water reservoirs is known about for some considerable time. Monitoring of surface water quality in the canals and ditches is an important part of the diagnosis process of eutrophication in freshwater ecosystems. There are several ways to assess water eutrophication. In this paper, assessment of water eutrophication based on diversity of macrophytes, index of trophic state and nutrients in the irrigation system of the manor-park complex in Breń (the south of Poland) is presented. The irrigation system constituting an integral part of the manor-park complex (from the 18th century) consists of open channels with a total length of about 1400 m with a total surface area 15 000 m^2. The water artificial watercourses with macrophytes can fulfill the role of the constructed wetland system which affected to the reduction in concentration of biogens in water flowing away from the irrigation system. The knowledge about the processes of self-purification is important for the management of small water reservoir like canals or ditches, where "water blooms" are frequent. The water analysis of surface water carried out during the vegetation seasons (from March to October) in the years 2015, 2016 and 2017 in the three measurment-control points situated in the supply ditch, the main park channel and the discharge channel. The concetration of amonium nitrogen (N-NH_4^+), nitrite nitrogen (N-NO_2^-), nitrate nitrogen (N-NO_3^-), phosphate-phosphorus (P-PO_4^{3-}) and also pH values, oxygen saturation and water temperature were assessed. Macrophytes inventories were carried out during the vegetation season of 2017, on five sections of channels and ditches. The results of the research showed a positive effect of the irrigation system in the park on the aquatic ecosystems. The results confirmed that the water in the canals has a eutrophic state, but as a result of slow water flow and macrophytes presence (e.g. *Typha latyfolia, Lemna minor, Sparganium ramosum*) causeed statistically signitifance decrease of biogenic compounds. It means that the presented a three ways of evaluation eutrophication risk of water may be successfully used to monitoring of surface water in the shallow water reservoirs like canals, ditches or ponds with controlled flow of water.

Key words: water quality; eutrophication; park channels; macrophytes; nutrients; Poland

1. INTRODUCTION

Ponds, ditches and cannals are particularly rich habitats and play an essential role in the conservation of aquatic biodiversity. Therefore it is necessary to assess their water quality but especialy their trophic state (Menetrey et al., 2005; Hou et al., 2013; Clarke, 2015). Water and hydro-engineering structures such as weirs on the irrigation channels can limit the fast outflow of water from the catchment (Mioduszewski et al. 2014) and influence on improvement of the landscape values of the rural manor parks by introducing a water element, which favourable irrigation and the development of the park vegetation. But they do not solve the problems of water quality and eutrophication. The park channels are generally shallow reservoirs with a limited water flow, which results in increased sedimentation and changes in biochemical processes occurring in the water. One of the major threats to this type of water body is eutrophication. Eutrophication of canals and ditches by over-fertilization with nitrogen and phosphorus causes a shift from a mainly submerged aquatic vegetation to a dominance of duckweed (Janse & Van Puijenbroek, 1998; Herzon & Helenius, 2008).

Water eutrophication has become a worldwide environmental problem in recent years, and understanding the mechanisms of water eutrophication will help for prevention and remediation of water eutrophication. Water eutrophication in lakes, reservoirs, estuaries and rivers is widespread all over the world and the severity is increasing, especially in the developing countries (Schindler, 2006; Yang et al., 2008; Schneider et al., 2013; Policht-Latawiec et al., 2014; Policht-Latawiec et al., 2016). The assessment of water eutrophication has been advanced from simple individual parameters like nutrients to comprehensive indexes like the Index of Trophic State (ITS) (Neverova-Dziopak, 2010) or Macrophyte Index for Rivers (MIR) (Szoszkiewicz et al., 2010a and 2010b).

Macrophytes are an important component of aquatic ecosystems and are required to be used broadly within the Water Framework Directive (WFD) (Directive, 2000/60/EC), to facilitate the establishment of good ecological status and general monitoring of ecological status. In addition to their ecological role, macrophytes are indicators of ecological quality in standing and flowing waters. In particular species and species groups of macrophytes are typical of specific types of waterbody and the degree to which they are adversely affected by types of antropogenic impact (Dawson, 2002; Thomaz & Ribeiro da Cunha, 2010; Lewin & Szoszkiewicz, 2012). The presence of macrophytes in water bodies is a guarantor of good ecological status, on the other hand, the undeniable aesthetic value (Sender & Jaruga, 2017). Plants such as *Typha spp.* or *Phragmites australis* in northern climates have an obvious annual cycle of aboveground biomass: new shoots start from zero biomass in early spring and grow at a maximum rate in spring and early summer (Kadlec & Knight, 1996). Nutrients are assimilated from the sediments by emergent and rooted floating-leaved macrophytes, and from the water in the free-floating macrophytes (Wetzel, 2001).

Selected macrophytes can be used successfully in phytoremediation of contaminated waters, particular those such as *Typha latifolia, Phragmites Australis*, *Glyceria aquatica, Sparganium ramonsum* and *Lemna minor* (Tatar & Öbek, 2014; Guittonny-Philippe et al., 2015; Laabassi et al., 2015; Sender & Jaruga, 2017). The macrophytes have several properties in relation to the treatment processes. The most important effects of the macrophytes in relation to the wastewater treatment processes are the physical effects of the plant tissues give rise to filtration effect and provide of surface area for attached microorganisms (Shah et al., 2014). Submerged macrophytes are of particular importance in aquatic ecosystems, as they link the sediment with the overlying water (Schneider & Melzer, 2003). Macrophytes play important roles in balancing lake ecosystem. They have capacity to improve the water quality by absorbing nutrients with their effective root system (Dhote & Dixit, 2007). They also affect the amount of oxygen concentration in the water through photosynthesis (Caraco et al., 2006).

Some functions of water channels, such as regulating water flow and nutrient retention, are likely to depend on the composition and structure of biological communities of ditches, though the issue remains poorly explored (Needelman et al., 2007; Herzon & Helenius, 2008). Small water reservoirs as channals or ditches and weirs on them can limit the fast outflow of water from the catchment (Mioduszewski et al. 2014).

Concentrations of phosphorus and nitrogen compounds in surface waters are being regulated in the Poland and European Union. Human activity has raised the concentrations of these nutrients, leading to eutrophication of inland waters, which causes nuisance growth of algae and other aquatic plants (Lewis et al., 2011). Also the increasing use of mineral fertilisers over the last decades has contributed to the appearance of numerous cases of water eutrophication, a new form of water pollution (Sala & Mujeriego, 2001). High pH values could encourage the release of nitrogen and phosphorus (Hou et al., 2013). Major advances in the scientific understanding and management of eutrophication have been made since the late 1960s. The control of point sources of phosphorus reduced algal blooms in many lakes (Schindler, 2006). Generally speaking, water eutrophication is caused by the autotrophy algae blooming in water (Yang et al., 2008). High concentrations of nutrients from the catchment are causing algal blooms in many water reservoir. Algal blooms induce eutrophic conditions, depleting oxygen levels needed by organic life, limiting aquatic plant growth by reducing water transparency, and producing toxins that can harm fish, benthic animals, and humans (Klemas, 2012).

The phenomenon of eutrophification, which occurs widely in the surface waters all over the world, its mainly identified with the biogenic compounds. The results of studies other reserchers shows, that the presented a three ways of evaluation eutrophication risk of water (based on nutrients, macrophytes index and trophic index) may be successfully used to monitoring of surface water in the shallow water reservoirs like canals, ditches, ponds and also rivers with controlled flow of water.

2. MATERIAL AND METHODS

2.1. Study area

The manor-park complex in Breń (longitude 50°12’48.76’’ N and latitude 20°57’4.19’’ E) was created in the 18th century (1750–1760) by Pfaffinger – garden designer from Vienna, as a baroque compositions (the historic french style park), commissioned by the Prince Józef Klemens Czartoryski. The manor-park complex is located 7 km north of Dabrowa Tarnowska (the Małopolskie Province) (Fig. 1). The area of the complex is about 15 hectares. In addition to the park, there are also manor hause from the 19th century and several historical objects in the areas of the complex. These include the alleys of the park, the representative entrance gate, the water channels surrounding the park, the romantic white bridge on the main channel, the labyrinths and the gardener's house. In 1786 the famous heraldry Ewaryst Kuropatnicki wrote that "*Breń, the Princes Czartoryski village, the most beautiful garden in all Galicia has*".

The object lies on a sandy plain situated in the catchment of the Breń River (Kowalik et al., 2015), which is the right-bank tributary of the Vistula River. The average altitude of park complex is 175,00 m a.s.l. According to the geographical division by Kondracki (2011), the manor-park complex in Breń is situated in the Carpathian Region (5), in the Western Carpathian province (51), in the macroregion of the Sandomierska Basin (512.4-5) and in the mesoregion of the Vistula Lowland (512.41), in terms of climate is considered as one of the warmest areas in this region.

The water supply to the park channels is provided by the irrigation system (Fig. 2) with parameters given in Table 1.

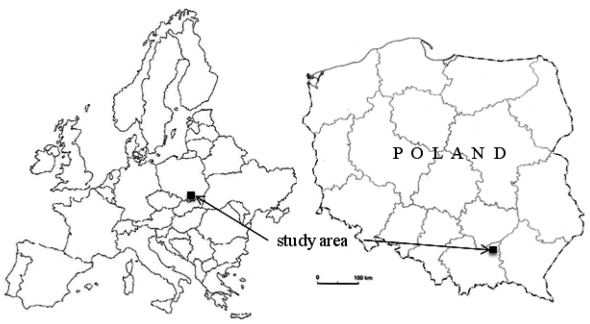

Figure 1. Location of study area

The first element of system is a three-span flap weir built across on the Breń river to damming up of the water (Fig. 2A) and then the water flow into the park complex by the supply ditch (Fig. 2B). Next, water running through a fish ponds (Fig. 2C). The irrigation system constituting an integral part of the manor-park complex consists of open channels: the main channel (Fig. 2D), the west channel (Fig. 2E) and the north channel (Fig. 2F) with two weirs (Fig. 2G). The last element of the system is the discharge ditch (Fig. 2H). The substrate material of the channels is loamy sand. The system function effectively during the vegetation period (March–October). The water catchment area of the Breń river is predominantly agricultural.

Table 1. Characteristics of researched watercourses

No.	Research sections	Lenght of watercourse	Average width of water table	Average depth of water
		[m]		
1	Supply ditch	270	0.60	0.35
2	Main channel	450	20.0	0.80
3	Discharge ditch	100	0.60	0.20
4	West channel	400	5.00	0.70
5	North channel	100	6.50	0.50

2.2. The Macrophyte Index

Field studies were carried out during the vegetation season of 2017, on five sections of manor-park complex channel and ditches (Table 1).

Field surveys were conducted using the Polish macrophyte approach, which enabled calculation of several macrophyte metrics. Firstly, a numerical index MIR (the Macrophyte Index for Rivers) was computed, which reflects watercourse degradation, especially their eutrophication. The assessment included macrophytes attached or rooted in parts of cannal bank that are likely to be submerged for more than 85% of a year length. The presence of each species was recorded with their percentage cover using following the nine-point scale: <0.1%, 0.1–1%, 1–2.5%, 2.5–5%, 5–10%, 10–25%, 25–50%, 50–75%, >75% (Szoszkiewicz et al., 2010a).

Based on the inventory of macrophytes species composition and their abundance, the Macrophyte River Index (MIR), which was referenced to the reference values for a given type of abiotic watercourse, was calculated for ecological status in the meaning of the WFD. The MIR index was calculated according to the following formula:

$$MIR = \frac{\sum (L_i \cdot W_i \cdot P_i)}{\sum (W_i \cdot P_i)} \cdot 10 \quad (1)$$

where: L_i – indicative value of species *i*, W*i* – weight (ecological tolerance) of species *i* according to the three-point scale of ecological amplitude of species and P_i – abundance of species *i* in a site in the nine-point scale.

The calculated value of the MIR indicator is compared with the obligatory ecological status/potential classes basis of the following legal act: Regulation of the Ministry of Environment dated 21 July 2016 establishing the way of classifying the state of uniform parts of surface waters and environmental quality standards for priority substances (2016) (Table 2).

2.3. Index of Trophic State

The method used is fundamentally different from traditional approach and based on the definition of trophic status as the existing state of the biotic balance in waters. It is characterized by easy interpretation of results and low costs (Neverova-Dziopak & Kowalewski, 2014).

Table 2. Classes of ecological status/potential of water based on MIR for the abiotic type of watercourse such as canals and dam reservoirs

Ecological status or potential	**Values of the MIR**
very good	≥46.8
good	(46.8–36.6>
moderate	(36.6–26.4>
poor	(26.4–16.1>
bad	<16.1

Figure 2. Location of measurement-control points and other elements of the irrigation system
Explanations: 1, 2 and 3 – location of the measurement-control points; A – three-span flap weir on the Breń River; B – the supply ditch; C – ponds; D – the main channel in the manor-park complex with a white bridge; E – the West channel; F – the North channel; G – two weirs to damming up of the water; H – the dischrge ditch.

ITS is a relatively new method for diagnosing eutrophication intensity. It analyzes the balance between production processes and organic matter decomposition through simultaneous measurements of oxygen saturation and pH of water. ITS is a versatile tool which can be applied in various types of water Dobies (Skwierawski, 2013).

The analysis of oxygen saturation and pH values were carried out during the vegetation seasons (from March to October) in the years 2015, 2016 and 2017 in the three measurement-control points situated in the supply ditch (1), the main channel (2) and the discharge channel (3) (Fig. 2). On site, the degree water oxygen saturation was measured with CO-411 oxygen meter, and the water pH was measured with CP-104 pehameter. In addition, the water temperature was measured synchronously with the pH and oxygen content.

The Integrated Index of Trophic State can be calculated according to equation:

$$ITS = \frac{\sum pH_i}{n} + a \cdot \left[100 - \frac{\sum [O_2\%]}{n}\right] \quad (2)$$

where: pH_i – pH value; $[O_2\%]$ – oxygen saturation measured synchronously with pH; a – an empirical coefficient; n – number of measurements (Neverova-Dziopak, 2010). Values of ITS index for waters of different trophic state showed in Table 3. One of the conditions of use Index of Trophic State (ITS) is the existence of a linear relationship between pH values and oxygen saturation in water.

Table 3. Values of ITS index for waters of different trophic state

State of biotic balance	Trophic state	ITS
Negative	Dystrophic	<5,7 ±0,3
	Ultraoligotrophic	6,3 ±0,3
Balanced	Oligotrophic	7,0 ±0,3
Positive	Mesotrophic	7,7 ±0,3
	Eutrophic	>8,3 ±0,3

2.4. The concetrations of biogenic compounds

Water samples were collected once a month during the vegetation seasons (from March to October) in the years 2015, 2016 and 2017 in the three measurement-control points situated in the supply ditch (1), the main channel (2) and the discharge channel (3) (Fig. 2).

The concetration of amonium nitrogen (N-NH_4^+), nitrite nitrogen (N-NO_2^-), nitrate nitrogen (N-NO_3^-) and phosphate-phosphorus (P-PO_4^{3-}) were assessed using flow colorimetric analysis on FIAstar 5000 apparatus.

2.5. Statistical analyses

The data set consisted of analytical results of water samples collected at the three measurement–control points located at the beginning, in the middle, and at the end of the irrigation system during 3 vegetation seasons (2015–2017) with a monthly frequency. For statistical analysis, the procedures provided by the program *Statistica version 12.5* were used. The analysis of the significance of differences between the values of indices measured in points was conducted using U Mann-Whitney test ($\alpha = 0.05$) to assess the effect of the irrigation system in the manor-park channels on water quality. A 5% significance level was used. A statistical method was chosen after checking data normality. For each analysed physicochemical index of water quality its minimum and maximum values were determined its arithmetic mean and coefficient of variance (CV) were computed. Moreover, the median and average value were calculated separately for each index and measurement point. Assessment of the water trophic state (ITS) performed based on the correlation relationship ($\alpha = 0.05$) between the oxygen saturation of water and pH values. In figures added: medians, minimum and maximum values, quartiles (25-75%) and correlation coefficients (r).

3. RESULTS

3.1. Assesment of water eutrophication based on macrophytes diversity

Qualitative and quantitative characteristics of macrophytes in the manor-park channels is given in Table 4. In total, 25 species of macrophytes were inventoried in the manor-park channels, of which 20 are indicator species in the MIR method. As showed in Fig. 3, the most richness of macrophytes was observed in the discharge ditch (18 species) then in the West channel (16 species), in the North channel (13 species), in the supply ditch (8 species) and least species inventoried in the main channel (only 4 species). This can be caused by a higher water flow, the depth of water and the strong shading of channel in relation to the other canals and ditches (Table 1).

The emergent macrophytes accounted more than 60% of the all observed plants in the water channels.

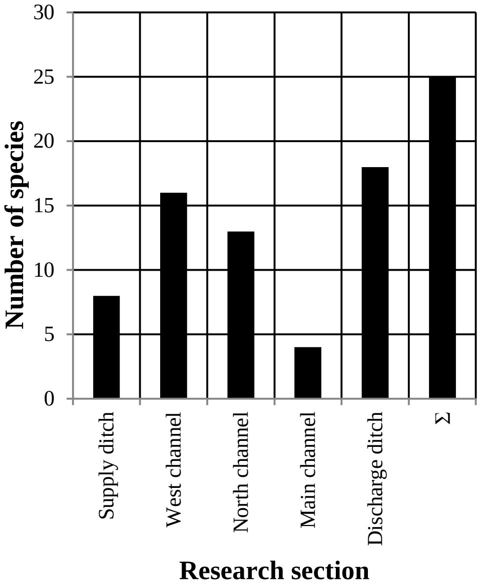

Figure 3. Species richness of the research sections

The submerged macrophytes were second abundant group of plants (16%). The free floating-species and algae accounted 8%.

Based on the range of values of the trophic (L) and ecological tolerance (W), waters in the channels acquired the characteristics of the eutrophic environment (Fig. 4).

With regard to the five classes system of ecological status/potential, according to the calculated value of the MIR index, the water in the park-channels was clasified as class III of the water quality and moderate ecological status/potential (Table 4).

The most frequently occurring macrophytes were *Typha latifolia* followed by *Glyceria Maxima* and *Lemna minor* (Table 4). Duckweed, because of low flow, it constitutes a rather compact phytocoenosis. It is worth noting that *P. australis* is abundant in the pond (before inflow to the park-complex), as well as in and the west channel. *Typha*

Table 4. Qualitative and quantitative characteristics of macrophytes in the manor-park channel

No.	Macrophyte species	The indicato value of species (L_i)	The weighting factor of species (W_i)	Place of the research				
				Supply ditch	Main channel	Discharge ditch	West channel	North channel
				The cover value of species (P_i)				
1	*Vaucheria sp.*	2	2	0	0	2	0	0
2	*Cladhopora sp.*	1	2	0	0	1	0	0
3	*Equisetum fluviatile*	5	2	0	0	1	0	0
4	*Potamogeton crispus*	4	2	0	0	3	0	0
5	*Potamogeton natans*	4	1	1	0	0	1	0
6	*Lemna minor*	2	2	2	0	1	3	9
7	*Spirodela polyrrhiza*	2	2	1	0	1	1	5
8	*Callitriche cophocarpa* Sendtn.	5	2	2	0	0	0	0
9	*Ceratophyllum demersum*	2	3	0	4	1	1	0
10	*Typha latifolia*	2	2	0	1	7	2	4
11	*Typha angustifolia*	3	2	0	1	0	1	0
12	*Glyceria fluitans*	5	1	0	0	1	0	0
13	*Glyceria maxima*	3	1	7	0	4	1	3
14	*Phalaris arundinacea*	2	1	2	0	0	0	0
15	*Sparganium erectum*	3	1	0	0	4	2	6
16	*Phragmites australis*	–	–	0	0	0	2	0
17	*Iris pseudacorus*	6	2	0	1	4	4	2
18	*Alisma plantago-aquatica*	4	2	1	0	3	1	1
19	*Carex pseudocyperus*	–	–	0	0	1	1	0
20	*Polygonum hydropiper*	3	1	1	0	3	0	1
21	*Peucedanum palustre* Moench	5	2	0	0	2	0	2
22	*Lythrum salicaria*	–	–	0	0	1	6	2
23	*Lycopus europeaus*	–	–	0	0	0	1	2
24	*Lysimachia vulgaris*	4	1	0	0	0	1	1
25	*Solanum dulcamara*	–	–	0	0	1	0	1
Values of the MIR				31.8	26.5	33.2	35.0	27.7
and ecological status / potential of water				moderate				

latifolia is far more abundant than *P. australis* at the study site, and is localized in the west and north channel, specifically in the discharge ditch. The plant species distribution at the study site depends on several factors, such as the water flow, the depth of water, the widght and the shady of channels.

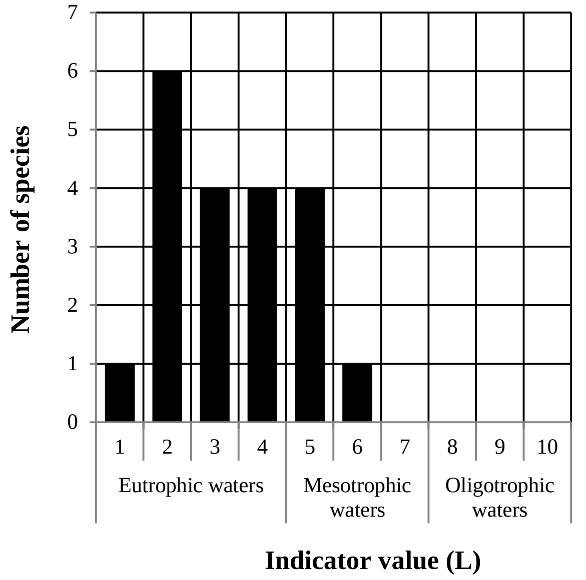

Figure 4. Distribution of the indicative value of species (L) of macrophytes identified during research

3.2. Assessment of trophic state based on oxygen saturation of water and pH value

Water pH was higher in the main channel and in the discharge ditch than in the supply ditch. The oxygen saturation in water showed similar trends. As revealed by Table 6 and Figs. 6–7, the mean pH value of inflow water was 7.36 and ranged from 6.93 to 8.23. However, at the outflow from the irrigation system, the pH values were ranging from 7.50 to 9.13. The oxygen saturation and pH values were statistically significant higher (↑) in the second and third measurement-control points than in the first point. In both analyzed cases between the second and third point was not found significant differences (↔) (Table 6; Fig. 5).

Among the three measurement-control points, the main channel exibited the highest average, minimum and maximum values of water temperature, but the coefficients of variation were similar for all the measurement points (Table 6; Fig. 8). The temperature of water in the supply ditch ranged from 5.4 to 23.3°C, while in the main channel, from 5.9 to 27.6°C, and in the discharge ditch for 5.9 to 26.7 °C. The coolest water flowed in the supply ditch: its 3-year average was 2.2°C lower than for the main channel and 1.8°C lower than for the discharge ditch. The average temperature of water in the main channel was only 0.4°C higher than in the discharge ditch.

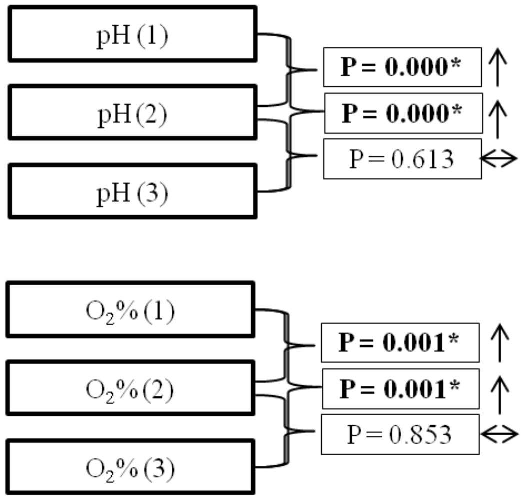

Figure 5. Results of U Manna-Whitney test
Note: ***bold** type indicates significant differences

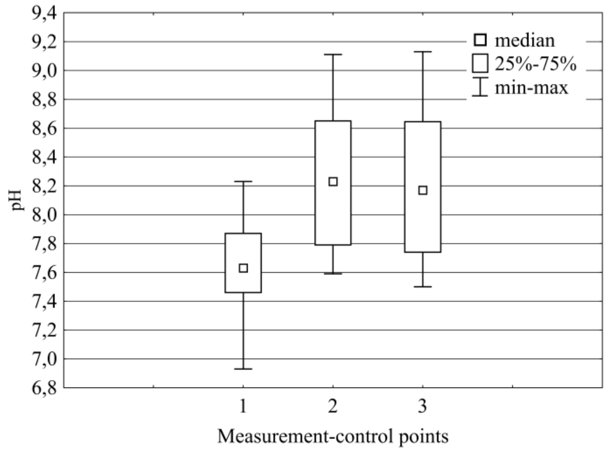

Figure 6. Changes of the pH values in the three measurement-control points

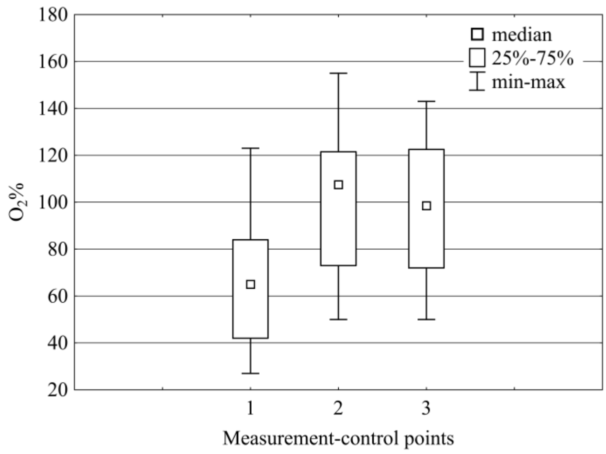

Figure 7. Changes of the oxygen saturation (O_2%) in the three measurement-control points

Statistical results are evident also in Table 5, which show the correlations of pH and oxygen saturation at the measurement points. The analysis shows that only in two measurement points relationship between pH and oxygen saturation was linear and statistically significant (P < 0.05).

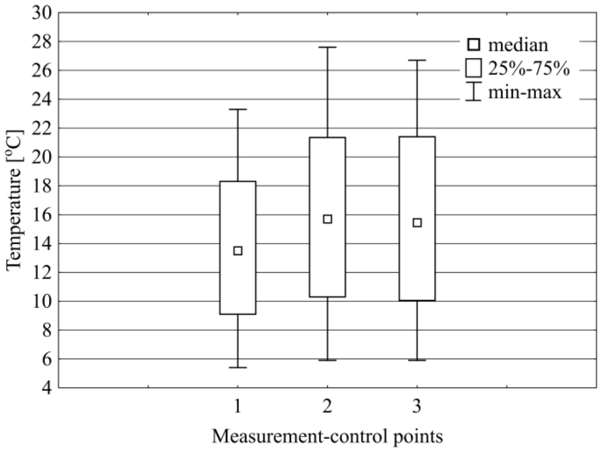

Figure 8. Temperature changes in the three measurement-control points

Table 5. Results of correlations analysis

Variable	pH (1)	pH (2)	pH (3)
O_2% (1)	r = 0.32 P = 0.124	–	–
O_2% (2)	–	**r = 0.75* P = 0.00**	–
O_2% (3)	–	–	**r = 0.69* P = 0. 000**

Note: ***bold** type indicates significant differences

There was a highly significant correlation between pH values and oxygen saturation in the main channel (r = 0.75, n = 24, P < 0.05) and the discharge ditch (r = 0.69, n = 24, P < 0.05) (Figs. 10–11). It was very weak a linear relationship between pH values and oxygen saturation in water in the supply ditch (r = 0.32, n = 24, P > 0.05) (Fig. 9).

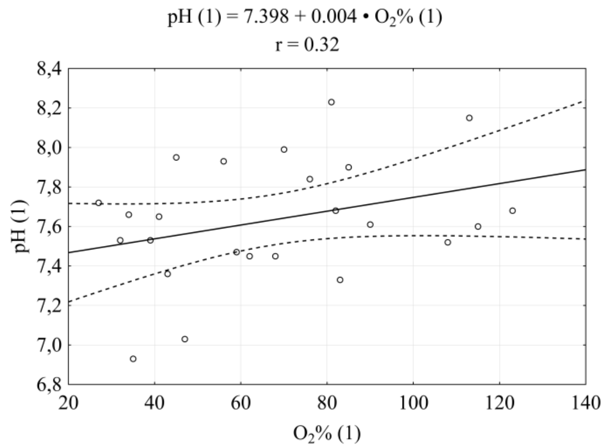

Figure 9. Correlations between pH and oxygen saturation in the supply ditch

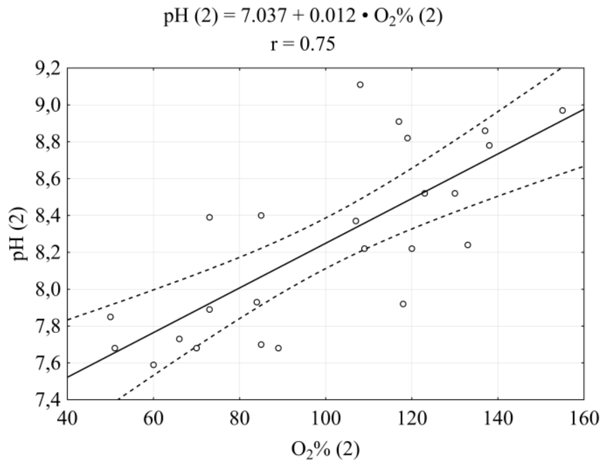

Figure 10. Correlations between pH and oxygen saturation in the main channel

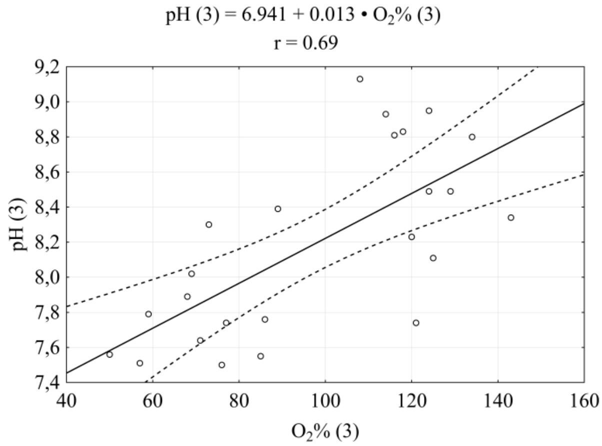

Figure 11. Correlations between pH and oxygen saturation in the discharge ditch

The highest values of ITS were found in the second measurement point (ITS = 8.25) and the third measurement point (ITS = 8.22), which means that the water has an eutrophic state. A slightly lower value (ITS = 7.76) was obtained for the first point, but it is statistically insignificant.

3.3. The concetrations of biogenic compounds

Overall, results of the research indicate that the irrigation system in the manor-park are highly effective in the treatment of domestic wastewater. Nutrients concentration were generally statistically significant lower (↓) in the main channel and in the discharge ditch than in the supply ditch and a trend was more evident. In all analyzed cases between the second and third point was not found significant differences (↔) (Table 6; Figs. 12–16).

The average concetration of nutrients was always high in the first measurement control point and gradually decreased in the second and third point (Table 6).

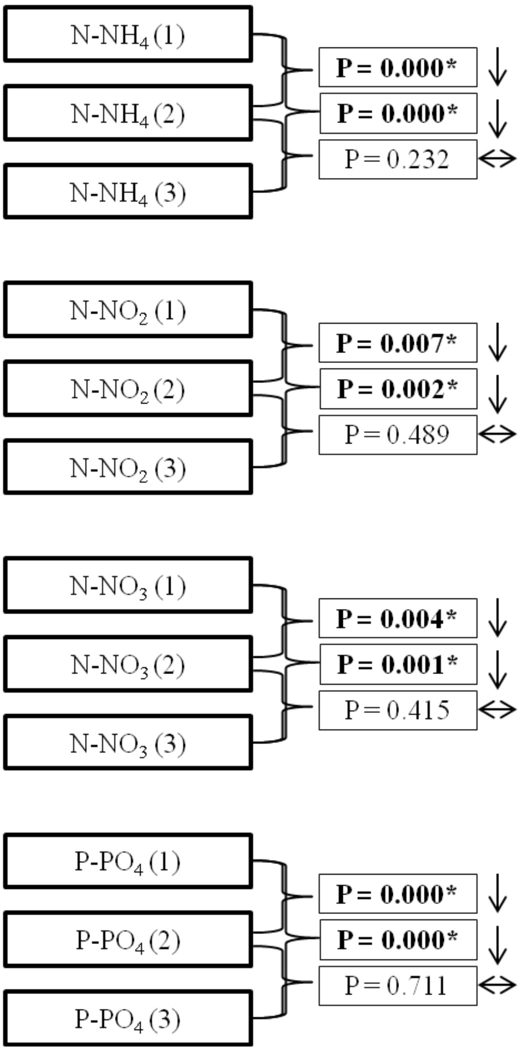

Figure 12. Results of U Manna-Whitney test

Note: ***bold** type indicates significant differences

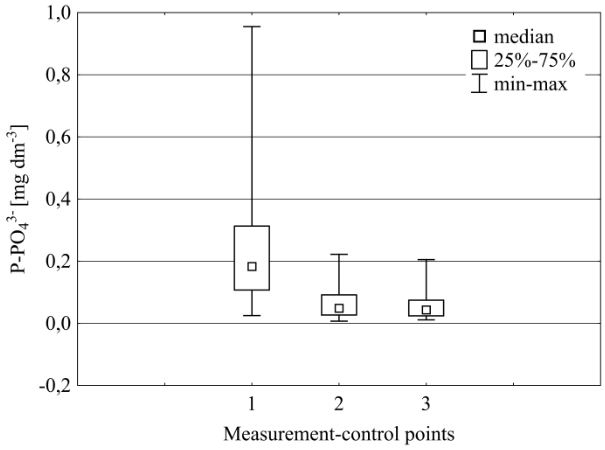

Figure 13. Changes of the phosphate-phosphorus ($P\text{-}PO_4^{3-}$) content in the three measurement-control points

The high maximum concetration of nutrients were in the first step of the irrigation system (in the supply ditch), and the low in the end step of system (in the discharge ditch). The coefficients of variation, showed that the greatest dynamics of changes occurred for all measured biogenic compounds. The cause may lie in illegal waste water discharge situated close to the irrigation system and in the intensive fertilisation of agriculturally-used soils.

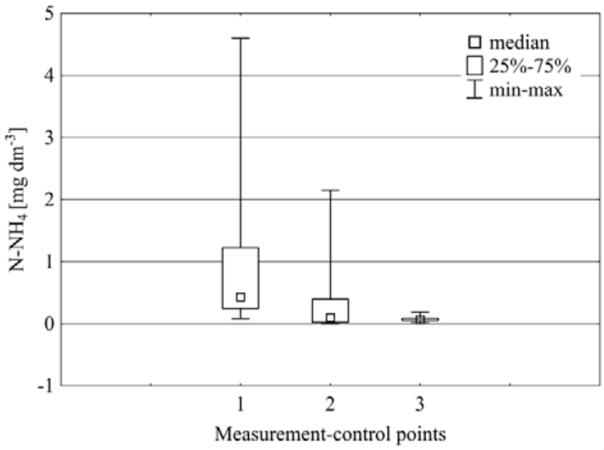

Figure 14. Changes of the amonium nitrogen ($N\text{-}NH_4^+$) content in measurement points

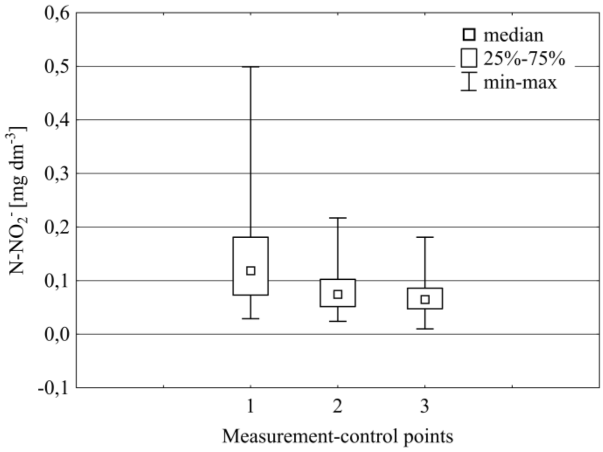

Figure 15. Changes of the nitrite nitrogen ($N\text{-}NO_2^-$) content in measurement points

4. DISCUSSION

The results from experimental study showed that exist different ways of water eutrophication assessment in shallow artificial channels and ditches, which include the macrophyte index, the biotic balance in water (acc. to pH values and oxygen saturation) and nutrients concetrations.

Water eutrophication caused a degradation of aquatic ecosystems, so the assessment methods and parameters should reflect the extents of aquatic ecosystem health (Yang et al., 2008; Vilmi et al., 2015) especially, this process is common in agricultural catchments of not regulated water and wastewater management (Tyler et al., 2012; Kanownik & Policht-Latawiec, 2015).

Table 6. Descriptive statistics of the physical and the biogenic indices of water in the manor-park channels

No.	Parameters	Place of the research*	Index value						
			Mnimum	Maximum	Average	Median	Standard deviation	Coefficient of variation	Sample sizes
1	Water temperature [^oC]	1	5.4	23.3	13.7	13.5	5.5	40.3	24
		2	5.9	27.6	15.9	15.7	6.5	40.9	24
		3	5.9	26.7	15.5	15.5	6.3	40.7	24
2	pH	1	6.93	8.23	7.63	7.63	0.31	4.07	24
		2	7.59	9.11	8.25	8.23	0.48	5.85	24
		3	7.50	9.13	8.19	8.17	0.53	6.42	24
3	Oxygen saturation degree [%]	1	27	123	67	65	29	43	24
		2	50	155	100	108	30	30	24
		3	50	143	97	99	28	29	24
4	$P\text{-}PO_4^{3-}$ [$mg \cdot dm^{-3}$]	1	0.03	0.96	0.25	0.18	0.23	93.74	24
		2	0.01	0.22	0.06	0.05	0.05	82.05	24
		3	0.01	0.21	0.06	0.04	0.05	86.48	24
5	$N\text{-}NH_4^+$ [$mg \cdot dm^{-3}$]	1	0.08	4.59	1.08	0.43	1.28	118.96	24
		2	0.00	2.15	0.32	0.10	0.52	159.59	24
		3	0.01	0.18	0.07	0.07	0.04	57.24	24
6	$N\text{-}NO_2^-$ [$mg \cdot dm^{-3}$]	1	0.03	0.50	0.15	0.12	0.11	71.98	24
		2	0.02	0.22	0.08	0.07	0.04	54.79	24
		3	0.01	0.18	0.07	0.07	0.04	57.24	24
7	$N\text{-}NO_3^-$ [$mg \cdot dm^{-3}$]	1	0.97	24.23	5.53	4.25	4.57	82.71	24
		2	0.77	7.52	3.01	2.79	1.66	55.32	24
		3	0.10	6.75	2.65	2.51	1.59	60.27	24

* 1 – the supply dich; 2 – the main channel in the park; 3 – the discharge ditch

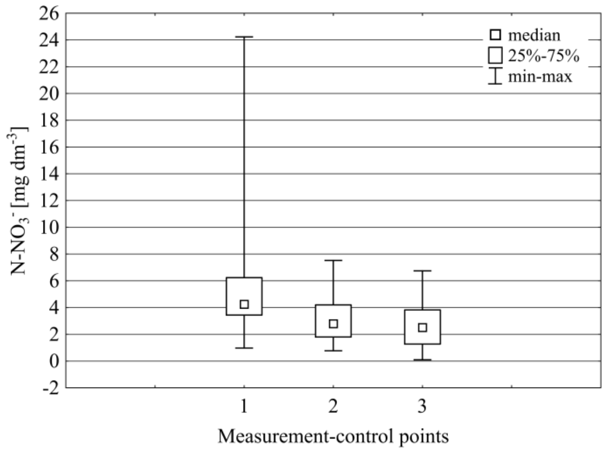

Figure 16. Changes of the nitrate nitrogen ($N\text{-}NO_3^-$) content in measurement points

Vegnetti et al., (2003) reported that nutrients concentrations significantly decrease along the water flow in the channels. This is a typical phenomenon frequently observed in natural purification processes. Tyler et al., (2012) observed that passage through irrigation ditches or canals has the potential to decrease nutrient loads and concentrations in outflow. Kronvang et al., (2005) observed that different N forms had different variation in concentration among the sampling sites. All Concentrations of nutrients in water samples significantly decreased from the supply ditch along the irrigation system to the discharge canal. The same relationship was observed in the manor-park channels in Breń. Concentration of $N\text{-}NH_4^+$ was relatively low and minimally changed among sampling sites. This result is consistent with the study in Danish streams, lakes, and estuaries, suggesting that $N\text{-}NH_4^+$ is quickly consumed by microorganisms or phytoplankton (Kronvang et al., 2005).

In another study, Laabassi et al., (2015) and Zeng et al., (2017) found decrease in nutrients concentration with the participation of emergent and floating macrophytes. It is therefore the basis for to use macrophytes to decrease and combat eutrophication in many shallow reservoir. Nutrients, light, water temperature, wide range of pH (6–9), water quality changes are factors that can strongly determine the diversity and composition of aquatic macrophytes (Albertoni et al., 2014; Dar et al., 2014; Shah et al., 2014). This is also evident in the researched park canals and ditches.

Bakker et al., (2010) reported, that submerged freshwater macrophytes decline with increasing eutrophication. This has consequences for ecosystem processes in shallow lakes and ponds as macrophytes can reduce algal blooms under eutrophic conditions. In the case of the irrigation system in the park only four species of submerged vascular plants, which favors the growth of algae and water blooms in the summer was observed.

According to Rosset et al., (2014) each trophic status, even the nutrient richest, brings an original contribution to regional diversity. Nevertheless, at the landscape scale, the proportion of hypertrophic waterbodies exceeds the proportion of less nutrient-rich systems. Conservation efforts should therefore promote the less rich small waterbodies currently lacking in the networks. Their results reinforce the notion of pond regional networks or 'pondscapes', where the regional biodiversity is promoted by the coexistence of a mosaic of trophic conditions in networks of waterbodies.

5. CONCLUSIONS

In conclusion, species richness of macrophytes in the park-channels is poor, but from year to year increase of the numbers of new taxa. The first macrophytes appeared a year after the reconstruction of the irrigation system.

The primary cause of moderate ecological status of water in the park-channels is inflow nutrients from the treatment of domestic wastewater from the Breń River catchment. The increase of nutrients concentrations in the irrigation system (especially in the supply ditch) is driven by higher nutrient levels in the Breń River.

Results demonstrated that research on phytoremediation of water pollution should focus much more on the use of existing water infrastructure with native macrophytes growing. At the end of the irrigation system, nutrients contaminants had been efficiently removed from water.

Among other findings, studies have evidenced a very strong reduction in concentration of biogens in water flowing away from the manor-park complex. Channels and ditches in the park play a key role of flow moderators and provide development of biodiversity.

It can be therefore concluded that a artificial watercourses, such as channels and ditchs used to irrigation of the manor-park complexs, can significantly favor natural self-purification processes leading to improved water quality and increase biodiversity.

Acknowledgements

This Research was finance by the Ministry of Science and Higher Education of the Republic of Poland. The work was carried out under Theme No. 4310 "Assessment of water quality and the risk of eutrophication in the artificial water reservoirs in the Małoplska Province" as part of the university competition for projects finance from a grant-in-aid for conducting research or developmental work aimed at development of young scholars and PhD students.

REFERENCES

Albertoni, E.F., Palma-Silva, C., Claudio Rossano Trindade, C. R. & Furlanetto, L.M., 2014. *Field evidence of the influence of aquatic macrophytes on water quality in a shallow eutrophic lake over a 13-year period*. Acta Limnologica Brasiliensia, 26, 2, 176–185. http://dx.doi.org/10.1590/S2179-975X2014000200008

Bakker, E.S., Van Donk, E., Declerck, S.A.J., Helmsing, N.R., Hidding, B. & Nolet, B.A., 2010. *Effect of macrophyte community composition and nutrient enrichment on plant biomass and algal blooms*. Basic and Applied Ecology, 11, 5, 432-439. https://doi.org/10.1016/j.baae.2010.06.005

Caraco, N., Cole, J., Stuart Findlay, S. & Wigand, C., 2006. *Vascular Plants as Engineers of Oxygen in Aquatic Systems*. BioScience, 56, 3, 219–225. https://doi.org/10.1641/0006-3568(2006)056[0219:VPAEOO]2.0.CO;2

Clarke, S.J. 2015. *Conserving freshwater biodiversity: the value, status and management of high quality ditch systems*. Journal for Nature Conservation, 24, 93–100.

Dar, N., Pandit, A. & Ganai, B., 2014. *Factors affecting the distribution patterns of aquatic macrophytes*. Limnological Review, 14, 2, 75–81. doi:10.2478/limre-2014-0008

Dawson, H. 2002. *Guidance for the field assessment of macrophytes of rivers within the STAR Project*. http://www.eu-star.at/frameset.htm

Dhote, S. & Dixit, S., 2007. *Water Quality Improvement through Macrophytes: A Case Study*. Asian J. Exp. Sci., 21, 2, 427–430.

Directive 2000/60/CE(2000), 2000. Framework directive of the European Parliament and of the Council of 23 October 2000 establishing a Framework for Community action in the field of water Policy

Guittonny-Philippe, A., Monnier, Y., Malleret, L., Coulomb, B., Combroux, I., Baumberger, T., Viglione, J. & Laffont-Schwob, I., 2015. *Selection of wild macrophytes for use in constructed wetlands for phytoremediation of* *contaminant mixtures*. Journal of Environmental Management, 147, 108–123, https://doi.org/10.1016/j.jenvman.2014.09.009

Herzon, I. & Helenius, J., 2008. *Agricultural drainage ditches, their biological importance and functioning*. Biological Conservation, 141, 1171–1183.

Hou, D., He, J., Lü, C., Sun, Y., Zhang, F., & Otgonbayar, K., 2013. *Effects of Environmental Factors on Nutrients Release at Sediment-Water Interface and Assessment of Trophic Status for a Typical Shallow Lake, Northwest China*. The Scientific World Journal, 2013, 716342. http://doi.org/10.1155/2013/716342

Janse, H. J. & Van Puijenbroek, P.J.T.M., 1998. *Effects of eutrophication in drainage ditches*. Environmental Pollution, 102, 1, 547–552.

Kadlec, R.H. & Knight, R.L., 1996. *Treatment wetlands.* CRC Press, Boca Raton, Florida, 893 pp.

Kanwonik, W. & Policht-Latwaiec, A., 2015. *Changeability of Oxygen and Biogenic Indices in Waters Flowing through Areas under Various Anthropopressures*. Polish Journal of Environmental Studies, 24, 4, 1633–1640. DOI: 10.15244/pjoes/26486

Klemas, V. 2012. *Remote Sensing of Algal Blooms: An Overview with Case Studies*. Journal of Coastal Research, 28, 1A, 34–43. https://doi.org/10.2112/JCOASTRES-D-11-00051.1

Kondracki, J. 2011, *Geografia regionalna Polski (Regional geography of Poland)*, Wydaw. Nauk. PWN Warszawa, 441 pp. (in Polish).

Kowalik, T., Bogdał, A., Borek, Ł. & Kogut, A., 2015. *The effect of treated sewage outflow from a modernized sewage treatment plant on water quality of the Breń River*. Journal of Ecological Engineering, 16, 4, 96–102. DOI: https://doi.org/10.12911/22998993/59355

Kronvang, B., Jeppesen, E., Conley, D.J., Sondergaard, M., Larsen, S.E., Ovesen, N.B. & Carstensen, J., 2005. *Nutrient pressures and ecological responses to nutrient loading reductions in Danish streams, lakes and coastal waters*. J Hydrol, 304, 274–288. https://doi.org/10.1016/j.jhydrol.2004.07.035

Laabassi, A., Harzallah, D. & Boudehane, A., 2015. *Performances of a constructed wetland treating planted with emergent and floating macrophytes under Algerian semi-arid climate*. Carpathian Journal of Earth and Environmental Sciences, 10, 4, 65–74.

Lewin, I. & Szoszkiewicz, K., 2012. *Drivers of macrophyte development in rivers in an agricultural area: indicative species reactions*. Central European Journal of Biology, 7, 4, 731–740. https://doi.org/10.2478/s11535-012-0053-0

Lewis, W.M., Wurtsbaugh, W.A. & Paerl, H.W., 2011. *Rationale for control of anthropogenic nitrogen and phosphorus to reduce eutrophication of inland waters*. Environ Sci Technol., 45, 24, 10300–103005. DOI: 10.1021/es202401p

Menetrey, N., Sager, L., Oertli, B. & Lachavanne, J.B., 2005. *Looking for metrics to assess the trophic state of ponds. Macroinvertebrates and amphibians*. Aquatic Conserv: Mar. Freshw. Ecosyst., 15, 653–664. doi:10.1002/aqc.746

Mioduszewski, W., Querner, E.P. & Kowalewski Z., 2014. *The analysis of the impact of small retention on water resources in the catchment*. Journal of Water and Land Development, 23, 41–51.

Needelman, B.A., Kleinman, P.J.A. & Strock, J.S., 2007. *Drainage Ditches. improved management of agricultural drainage ditches for water quality protection: An overview*. Journal of Soil and Water Conservation, 62, 4, 171–178.

Neverova-Dziopak, E. & Kowalewski, Z., 2014. *New approach to trophic state assessement of running waters in Poland*. Meteorol. Hydrol. Water Manage., 1, 1, 15–22. DOI: https://doi.org/10.26491/mhwm/20551

Neverova-Dziopak, E. 2010. *Fundamentals of Anthropogenic Eutrophication Management (Podstawy zarządzania eutrofizacją antropogeniczną).* Monografia. Kraków: Wyd AGH, 131 pp. (In Polish).

Polich-Latawiec, A., Kanownik, W. & Jurek, A., 2016. *The effect of cooling water discharge from the power station on the quality of the Skawinka river water*. Carpathian Journal of Earth and Environmental Sciences, 11, 2, 427–345.

Policht-Latawiec, A., Bogdał, A., Kanownik, W., Kowalik, T., Ostrowski, K. & Gryboś, P., 2014. *Quality and Usable Values of Small Flysch River Water*. Annual Set The Environment Protection, 16, 1, 546–561.

Regulation of the Ministry of Environment dated 21 July 2016 establishing the way of classifying the state of uniform parts of surface waters and environment al quality standards for priority substances (2016).

Rosset, V., Angélibert, S., Arthaud, F., Bornette, G., Robin, J., Wezel, A., Vallod, D. & Oertli, B. 2014. *Is eutrophication really a major impairment for small waterbody biodiversity?*. J Appl Ecol, 51, 415–425. doi:10.1111/1365-2664.12201\

Sala, L. & Mujeriego, R., 2001. *Cultural eutrophication control through water reuse.* Water Sci Technol., 43, 10, 109–116.

Schindler, D.W. 2006. *Recent advances in the understanding and management of eutrophication.* Limnology and Oceanography, 51, 1, 2, 356–363. doi: 10.4319/lo.2006.51.1_part_2.0356.

Schneider, S. & Melzer, A., 2003. *The Trophic Index of Macrophytes (TIM) – a New Tool for Indicating the Trophic State of Running Waters*. Internat. Rev. Hydrobiol., 88, 1, 49–67.

Schneider, S.C., Kahlert, M. & Kelly M.G., 2013. *Interactions between pH and nutrients on benthic algae in streams and consequences for ecological* *status assessment and species richness patterns*. Science of The Total Environment, 144, 73–84. https://doi.org/10.1016/j.scitotenv.2012.11.034

Sender, J. & Jaruga, C., 2017. *Eutrophication of water reservoirs and role of macrophytes in this process*. Ecological Engineering, 18, 3, 227–244 (in Polish). DOI: 10.12912/23920629/69374

Shah, M., Hashmi, H. N., Ali, A., & Ghumman, A. R., 2014. *Performance assessment of aquatic macrophytes for treatment of municipal wastewater*. Journal of Environmental Health Science and Engineering, 12, 106. http://doi.org/10.1186/2052-336X-12-106

Skwierawski, A. 2013. *The use of the integrated trophic state index in evaluation of the restored shallow water Dobies*. Ecological Chemistry and Engineering. A, 20, 11, 1275–1283. DOI: 10.2428/ecea.2013.20(11)115

Szoszkiewicz, K., J. Zbierska, Jusik, S. & Zgola, T., 2010a. *Macrophyte Method for River Assessment – Manual for the assessment and classification of ecological status of running waters based on the aquatic plants [Makrofitowa metoda oceny rzek. Podręcznik metodyczny do oceny i klasyfikacji stanu ekologicznego wód płynących w oparciu o rośliny wodne]*. Bogucki Wydawnictwo Naukowe, Poznan., 82 pp. (In Polish).

Szoszkiewicz, K., Jusik, S., Lawniczak, A.E. & Zgola, T., 2010b. *Macrophyte development in unimpacted lowland rivers in Poland*. Hydrobiologia, 656, 1, 117–131. https://doi.org/10.1007/s10750-010-0439-9

Tatar, Ş.Y. & Öbek, E., 2014. *Potential of Lemna gibba L. and Lemna minor L. for accumulation of Boron from secondary effluents.* Ecological Engineering, 70, 332–336. https://doi.org/10.1016/j.ecoleng.2014.06.033

Thomaz, S.M. & Ribeiro da Cunha, R., 2010. *The role of macrophytes in habitat structuring in aquatic ecosystems: methods of measurement, causes and consequences on Animals assemblages' composition and biodiversity*. Acta Limnol. Bras., 22, 2, 218–236. http://dx.doi.org/10.4322/actalb.02202011

Tyler, H.L., Moore M.T. & Locke, M.A., 2012. *Influence of Three Aquatic Macrophytes on Mitigation of Nitrogen Species from Agricultural Runoff*. Water, Air, & Soil Pollution, 223, 6, 3227–3236. https://doi.org/10.1007/s11270-012-1104-x

Vegnetti, R., Miana, P., Fabris, M. & Pavoni B., 2003. *Self-purification ability of a resurgance stream*. Chemosphere, 52, 1781–1795.

Verdonschot, R.C.M., Keizer-Vlek, H.E. & Verdonschot, P.F.M., 2011. *Biodiversity value of agricultural drainage ditches: A comparative analysis of the aquatic invertebrate fauna of ditches and small lakes*. Aquatic Conservation: Marine and Freshwater Ecosystems, 21, 715–27.

Vilmi, A., Karjalainen, S.M., Landeiro, V.L. & Heino, J., 2015. *Freshwater diatoms as environmental indicators: evaluating the effects of eutrophication using species morphology and biological indices*. Environ Monit. Assess., 187; 243. https://doi.org/10.1007/s10661-015-4485-7

Wetzel, R.G., 2001. *Limnology (3rd ed.),* Academic Press, San Diego, 1006 pp.

Yang, X., Wu, X., Hao, H. & He, Z., 2008. *Mechanisms and assessment of water eutrophication*. Journal of Zhejiang University, 9, 3, 197–209. http://doi.org/10.1631/jzus.B0710626

Zeng, L., He, F., Zhang, Y., Liu, B., Dai, Z., Zhou, Q. & Wu, Z., 2017. *How submerged macrophyte restoration promotes a shift of phytoplankton community in a shallow subtropical lake*. Pol. J. Environ. Stud., 26, 3, 1363–1373. DOI: 10.15244/pjoes/68228

Received at: 15. 12. 2017
Revised at: 12. 01. 2018
Accepted for publication at: 02. 02. 2018
Published online at: 05. 02. 2018