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Changes in Water Quality for Sprinkler Irrigation in Selected Lakes of the Poznan Lake District

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ABSTRACT

The rapidly changing quality of irrigation water requires urgent attention to understand and predict the long-term effects on soils and food crops, especially in a situation of global freshwater scarcity. The aim of the research was to assess changes in water quality in two selected lakes located in Poland in 2009–2016. The study was carried out in terms of the possibility of using selected reservoirs as sources of water for sprinkler irrigation of agricultural crops. The presented analysis was compared with a similar one carried out in 1999–2006 and 2004–2009 to determine the historic and present water quality state. Results indicate, that the source of pollution of the lakes is most often outflows from sewerage systems, the precipitation and surface runoff from the catchment areas of these lakes, which are mainly used as agricultural land. In Lake Niepruszewskie, the oxygen conditions, water transparency, phosphorus content, sestone dry matter and coliform titre increased, while the biological oxygen demand (BOD5), nitrogen, and chlorophyll content decreased. According to present research, in the Strykowskie Lake, the phosphorus content and BOD5 decreased, while the sanitary condition, nitrogen content and oxygen conditions deteriorated. The reduction of mineral fertilization in recent years has reduced the degradation of the lakes and allowed the water quality to remain in Class III of purity. Despite the visible improvement in the general condition of both studied lakes, constant monitoring of their quality is necessary, which is obligatory for the water from these reservoirs to be used for sprinkler irrigation of crops.

Keywords: biological oxygen demand, faecal coli, Secchi disc, soluble oxygen; water-saving irrigation, water purity.

INTRODUCTION

Effective irrigation is the controlled use of multiple water sources at the right time to increase or maintain crop production. Globally, irrigation is the highest consumptive use of freshwater (Bruinsma and Food and Agriculture Organization of the United Nations, 2003). With the increase of agricultural production to ensure global food security irrigation will increasingly be called upon to help meet this demand (Malakar et al., 2019). Hence, it is of great importance to continuously monitor the quality of water used in the irrigation process, which affects the quality of soils, and ensures proper crop growth and finally long-term food quality. There is a need to assess surface water quality for proper water resource management (Grzywna and Bronowicka-Mielniczuk, 2020). Long-term and regular research is a great source of information for water resource managers in regions and countries.

The area of Poland is located in a temperate climate, which is why the annual rainfall is very variable and is one of the lowest in this part of Europe. During the vegetation period in Poland there is a negative water balance, therefore field crops can use only water resources accumulated in the winter. Farmers more and more often have to use intervention irrigation, which is why they decide to change the production profile. Farmers give up the cultivation of cereals and start cultivating species that are profitable to irrigate, e.g. vegetables (Rolbiecki et al., 2021), berry bushes (Rolbiecki et al., 2002), orchards and vineyards (Jagosz et al. 2020) or phytomelioration plantings (Klimek et al., 2009). Unfortunately, scarce surface water resources are compounded by their insufficient quality, which makes optimal irrigation difficult. Published reports on the quality of surface waters in Poland, indicate a progressive deterioration of their quality, mainly due to progressing eutrophication. In order to increase the resistance of Polish agriculture to water shortages, it is necessary to not only to retain as much water as possible at the point of precipitation, but above all to protect the existing water sources used for irrigation.

Poland is a country rich in lakes, which are the main source of water used for sprinkler irrigation of field crops. Their number in the Great Poland-Kuyavia Lakeland is over 7,000 (with an area greater than or equal to 1 ha), with a total area of 281,377 ha (Choiński, 2006). There are 62 lakes with an area of over 100 ha, 58 lakes with an area of 51–100 ha and 679 lakes with an area of up to 50 ha within the boundaries of the Greater Poland province (Kondracki, 2022). Unfortunately, most of them belong to more or less eutrophic reservoirs. The protection of these water reservoirs consists primarily in finding ways to slow down and stop eutrophication processes or to minimize its negative consequences by limiting the flow of nutrients from the catchment area to the reservoir. The assessment of lake waters carried out by (WIOŚ, 2017) showed that out of 26 examined lakes, as many as 21 lakes were classified as reservoirs of poor water quality. The poor quality of these lake waters in the Greater Poland province was related to point sources of pollution, such as: pollution from agricultural areas, water withdrawal for the needs of the population and industry, development of existing and creation of new recreational areas, and insufficient sanitation of villages (WIOŚ, 2016). The opinion that the purity of waters in the Greater Poland province, as in the whole country, has been steadily deteriorating over the last several years is firmly established (Burchardt, 1995; Gołdyn, 1991; Jabłoński, 1994; Szyper, 1992). According to Gołdyn (1991), 60% of water flowing in rivers in Greater Poland province is degraded. This means that they do not meet the water purity standards.

After accession to the European Union, Poland was obliged to implement the Water Framework Directive (2000/60/EC), whose main objective was to achieve good ecological and chemical status of surface waters by 2015. Unfortunately, as shown by the results of basic and regional monitoring, carried out in 2009–2016 by WIOŚ (2017) in Poznan, out of the 84 surveyed lakes (over 100 ha or smaller, important for the region due to economic, natural and recreational values), only three of them were characterized by a very good condition of water classified as Class I of purity. Class II waters were determined in 28 lakes with a total area of 4,783.5 ha, i.e. 27.7% of the area surveyed over the period of eight years. Class III purity waters were determined for 55 reservoirs with a total area of 7,216.4 ha, i.e. 41.9% of the area of the examined lakes. In 38 surveyed lakes, the water quality did not correspond to any of the purity classes, which is why they were considered out-of-class due to heavy pollution (WIOŚ, 2017).

The water quality of a given water reservoir depends on many factors, and the nature of the areas directly adjacent to the lake often plays a decisive role. The amount of inflowing pollutants is most often associated with the type of catchment located in the vicinity of water reservoirs. Water degradation may also be affected by the supply of pollutants from much more distant areas, e.g. in the form of acid rain. Lakes located in agricultural catchments are exposed to a significant pollution load and progressive degradation (Chao et al., 2023; Lone et al., 2018; Negussie et al., 2011; Olando et al., 2020). Sources of pollution, especially of biogenic components, are both area-wide (field fertilization and chemical treatments) and point-based (homesteads, septic tanks, floodplains). Because these sources are widely dispersed and overlapping, they are often difficult to separate and quantify. Regardless of the origin and migration routes, the recipients of a significant load of pollutants are lakes, where their accumulation and biological processing (self-purification) takes place. The negative effect of this process is progressive eutrophication, often leading to the degradation of water bodies (Janicka et al., 2016; Kajak, 1979; Yao et al., 2018). Most reservoirs were monitored only sporadically, therefore these studies are not sufficient to analyze changes in water quality in the medium term, as it requires more detailed observations.

The aim of the research presented in this paper was to assess changes in water quality in two selected lakes of the Poznan Lake District in the years 2009–2016. Determined were the historic and present water quality state. The study was carried out in terms of the possibility of using Niepruszewskie Lake and Strykowskie Lake as sources of water for sprinkler irrigation of agricultural crops. The presented analysis was compared with a similar one carried out in the years 1999–2006 and 2004–2009 by Przybyła et al. (2006, 2011).

MATERIAL AND METHODS

The paper presents the results of water quality analyzes of two typical lakes of the Poznan Lake District named Niepruszewskie Lake and Strykowskie Lake. The assessment of the water quality of both lakes was carried out in the spring and summer, i.e. in growing season of each year in the years 2009–2016. The results of water quality tests of these two lakes were obtained from the laboratory of the Department of Land Reclamation, Environmental Development and Spatial Management of the Poznan University of Life Sciences.

The research was carried out in accordance with the methodology published by (Kudelska et al., 1994), which is recommended in the basic monitoring of lakes. The following determinations were carried out as part of the study: pH, soluble oxygen (mg $O_2 \cdot dm^{-3}$), biological oxygen demand (BOD5) (mg $O_2 \cdot dm^{-3}$), total ortophosphates (mg $P \cdot dm^{-3}$), phosphorus (mg $P \cdot dm^{-3}$), mineral nitrogen content ($N\text{-}NH_4 + N\text{-}NO_3$) (mg $N \cdot dm^{-3}$), salt content (mg$\cdot$dcm^{-3}), conductivity (10 mS), electrolytic conductivity (µS cm^{-1}), chlorophyll a (mg m^{-3}), dry matter of seston (mg m^{-3}), water transparency using Secchi disc (m), faecal coli form test, phytoplankton by Phytoplankton Multimetric for Polish Lakes (PMPL) and phytobenthos by Multimetric Diatom Indicator for Lakes (MMDI). Water tests concerned the determination of total salinity expressed by the electrolytic conductivity of water. Water samples were taken at monthly intervals during the growing season. The applied methodology is consistent with the methods of water salinity testing adopted by the FAO (Hermanowicz and Dojlido, 2005). Water samples were taken at monthly intervals during the growing season. Samples for laboratory analyses of the physico-chemical properties of irrigation water were collected as primary samples. They were collected at the shore water intakes for the sprinkler, before the inlet to the suction chamber from a depth of 0.5 to 1.0 m. The bucket attached to the rope was immersed in water and filled completely. After taking it to the surface, the first portion of the collected water was rinsed in the sample vessel and the bucket. After emptying the vessels, the water sample was again taken and poured into the bucket. Sampling was repeated until the bucket was full. Then, the contents of the bucket were thoroughly mixed with a glass rod, rinsed with the first portion of the collected water, and poured into a prepared plastic vessel with a tight closure, with a volume of 0.5 liters. During transport, the collected samples were protected against damage, spillage and contamination. Then, the vessels with the samples were placed in a thermos with a cooling insert, preventing to the temperature increase of the collected samples.

Collecting water samples near irrigation water intakes was based on the recommendations of the Polish Standard: PN-EN ISO 5667-6:2016-12 (2016) and their preservation in accordance with the Polish Standard: PN-EN ISO 5667-3:2013 (2013). An indicator characterizing the chemistry of water is the concentration of soluble mineral salts. A concentration of 100–300 mg dm^{-3} is considered safe in the tested soil and climatic conditions. The upper limits of permissible concentrations due to the fear of water salinity are in the range of 2000–4000 mg dm^{-3} (Thorne and Peterson, 2010). The research carried out in 2009–2016 as part of the continuity of water quality research was compared with the results of the assessment carried out in previous years, published by Przybyła et al. (2006, 2011).

These reservoirs are dammed lakes with retention capacity (for irrigation purposes) of 3.9 million m^3 and 4.3 million m^3 of water respectively (Przybyła et al., 1996). The studied lakes are located in catchments of a typically agricultural character, characteristic of the Poznan Lake District and the whole of Greater Poland province (Przybyła et al., 2011). These catchments are exposed to a significant pollution load and progressive degradation (Ilnicki, 1992, 1998; Pułyk and Tybiszewska, 1996; Szyper, 1992). Moreover, as stated by Zbierska and Ławniczak (2001), the parameters of the catchment area in which the Niepruszewskie and Strykowskie Lakes are located, with dominance of arable land (72%) and low forest cover (12%), are insufficient for wastewater treatment. The authors also indicate a potentially high threat to the waters of these lakes from point and area pollution. Sources of pollution, especially of nutrients, are both area-related (field fertilization and chemical tratments) and point-based (homesteads, septic tanks, floodplains). Because these sources are widely dispersed and overlapping, they are often difficult to separate and quantify. Regardless of the origin and migration routes, the recipients of a significant load of pollutants are lakes, where their accumulation and biological processing (self-purification) takes place. The negative effect of this process is progressive eutrophication, often leading to the degradation of water bodies (Giercuszkiewicz-Bajtlik, 1987; Ilnicki, 1998; Kajak, 1979; Reddy et al., 2018; Ukaogo et al., 2020).

The boundaries of the catchment were determined on the basis of the Atlas of the Hydrographic Division of Poland (Czarnecka, 2005). The physiographic characteristics and the management of the basins of individual lakes were made on the basis of topographic maps in the scale of 1:50,000 according to the Corine Land Cover 2006 database (Kondracki, 2022; WIOŚ, 2003, 2004, 2005, 2008). The description of the soils was made on the basis of the Map of Soils of the Poznan Lake District made in the Department of Soil Science and Reclamation of the Poznan University of Life Sciences.

Water samples from lakes were collected at the edge of water intakes for semi-permanent sprinklers, before the inlet to the suction chamber, from a depth of 0.5 m to 1.0 m. Water samples from Lake Strykowskie were collected at three points near the pumping stations located in Jeziorki, Sapowice and Strykowo. Water samples from Lake Niepruszewskie were collected in two points next to the pumping stations located in Cieśle and Zborowo. In total, in the period from April 28, 2009 to October 13, 2016, 48 samples were taken from Lake Strykowskie and 32 samples from Lake Niepruszewskie. Physical and chemical analyzes of waters were performed in the field and in the laboratory of the Department of Land Improvement, Environmental Development and Spatial Management of the Poznan University of Life Sciences using standard methods. The analysis of the test results and the assessment of water quality were performed on the basis of the Regulation of the Minister of the Environment of 2004, which was used in water monitoring until 2008 (Przybyła et al., 2006, 2011). This regulation was also applied to the results from 2009 in order to maintain the continuity of the analysis and the comparability of the results. No reference was made to the new Regulation of the Minister of the Environment of 2008 due to the change in the classification system used in it and the determination of limit values only for selected physical and chemical indicators and only for water of Class I and II. Due to the fact that less than twelve observations per year were made to determine the water quality class, in accordance with the Regulation of 2004, the worst value of the examined indicators was adopted.

RESULTS AND DISCUSSION

Presentation of research area

Lake Niepruszewskie is located on the border of the Dopiewo and Buk communes, in a post-glacial trough flowing through the Samica Stęszewska River (Czarnecka, 2005). Lake Niepruszewskie is a polymictic ribbon lake (length 4.9 km, width 0.7 km), with an average depth of 3.1 m and a maximum depth of 5.2 m. According to the data of the Inland Fisheries Institute in Olsztyn, the lake area is 242.3 ha, and the volume is 7,578.3 thousand m^3 (Jańczak, 1996). Due to its small depth, long shoreline (11.1 km) and unfavorable parameters of the immediate catchment, the lake is classified as the 3rd category of susceptibility to degradation (Pułyk and Tybiszewska, 1996). The main watercourse supplying the lake is the Samica Stęszewska River (water quality is presented in the paper by (Zbierska and Ławniczak, 2001), flowing from the north-west through a not very wide and heavily overgrown channel. Moreover, drainage ditches, periodically dry, draining the surrounding fields and meadows (Zbierska and Ławniczak, 2003a, 2003b). The outflow of the Samica Stęszewska River is located in the southern part of the reservoir and is regulated by a reinforced concrete weir. The weir was built in the past to provide water for irrigation in agriculture, but currently it is not used. The damming of water has a positive effect on the functioning of the entire lake ecosystem, improving the conditions for self-purification of water by improving the unfavorable ratio of the lake volume to the length of the shoreline and the area of the active bottom to the volume of the epilimnion. Water damming also stabilizes the range and functioning of the macrophyte zone in the littoral as a biogeochemical barrier. Emerging vegetation is strongly developed along almost the entire shoreline of the lake (it is 90% of the length of the shoreline, except for the beach in Niepruszewo), forming a wide belt of reeds, mainly reeds and sticks, manna and sedge. The extensive littoral zone, covering an area of approx. 18 ha, i.e. approx. 7.4% of the water surface, effectively protects the lake against direct flow of pollutants from the coastal areas. From the eastern side, a wide strip of meadows and willow-alder thickets adjoins the lake, also playing an important protective role. This body of water is a flow-through reservoir, elongated from south to north. The bottom of the lake bowl is shallow and has a regular shape. There is a thick layer of sediment at the bottom. Most of the shores of the lake are low and wet, covered with a wide zone of rushes. The parameters unfavorable for the lake, affecting the significant susceptibility of the reservoir to degradation, is the long shoreline in relation to the volume of the lake, increasing the possibility of contact of the water mass in the lake with the surrounding area. The lack of stratification of the lake's waters, which is conducive to high productivity of the reservoir, and the ratio of the active bottom area to the volume of the epilimnion, additionally enriches the lake with nutrients from bottom sediments (WIOŚ, 2005, 2006, 2009).

The catchment area of the lake is agricultural, with quite numerous residential and recreational buildings in the villages Niepruszewo, Zborowo and Cieśle, located close to the shores of the lake. Built-up areas are not sewered, which favors the flow of pollutants into the lake's waters and contributes to a significant degree of their eutrophication. It was not until 2008 that a municipal sewage treatment plant was launched in Niepruszewo for the towns of Kalwy, Niepruszewo, Cieśle, to which sewage from septic tanks is delivered, and in 2010 the construction of a sewage system began. In the immediate basin of the lake, with an area of approx. 7.0 km^2, arable land predominates, constituting 64.3% of the area, and meadows 18%. Agricultural production there is intensive, characterized by high fertilization and a simplified sowing structure, as well as concentration of animal production, especially pigs (Kupiec et al., 2008). Small forested areas occur only on the south-eastern side of the lake. The lake is used for fishing and recreation. There are two bathing beaches in Niepruszewo and Zborowo. To the south of the lake runs the A2 motorway connecting Poznan with Berlin and there are excavations of the now closed lake chalk mine. In the western part of the lake's catchment, soils made of loose sands predominate, and on the eastern side, soils made of boulder clays and clayey (light) clay sands prevail, and in some places the top layers of the soil are heavily anthropogenically transformed. In the immediate vicinity of the lake there are soils of glacial channels made of light clay sands.

Surface sources of pollution are primarily water runoff from fields located in the entire catchment area of the lake. For this reason, the lake and the source section of the Samica Stęszewska River have been classified as waters sensitive to nitrates and at risk of eutrophication. On the other hand, the catchment area of the Samica Stęszewska River, based on the Regulation of the Director of the Regional Water Management Authority in Poznan of 2003 and 2008 was classified as particularly vulnerable areas for the presence of nitrates of agricultural origin (Kupiec et al., 2008). Potential sources of pollution of both studied lakes are: residential and farm buildings in the villages of Niepruszewo, Ciesle, Kalwy, Zborowo, Tomice and Mirosławki, located in the immediate vicinity of the lakes, summer cottages located directly on the shores of the waters (without sewage systems and sewage treatment plants) and recreational use of the lakes, inflow of surface waters (ditches and watercourses), which are often the receiver of domestic and farm sewage (including from animal production), intensive agricultural production on arable land (especially on large-area farms in Niepruszewo), fishing use of lakes (stocking, bait, shore penetration). In the years 1998–1999, the scale of the direct threat to Lake Niepruszewskie decreased significantly as a result of the closure of the distillery in the Niepruszewo Farm and the elimination of the discharge of burdensome sewage directly into the lake. Lake Strykowskie with an area of 305 ha, it is one of the largest lakes of the Poznan Lake District. It is fed mainly by a tributary from Dobierzyn and by smaller ditches draining the immediate basin of the lake (Czarnecka, 2005). Trench Strykowski flows from the reservoir, which flows through Trench Kąkolewski into the Mogilnica River. The lake is strongly elongated in the northeast to south-west direction. It belongs to the lakes susceptible to degradation due to the strongly developed shoreline and small depth (average 4.5 m). The shores of the reservoir are gentle and densely covered with reed vegetation. The water in the lake is dammed for agricultural irrigation. Near the village Strykowo the lake is surrounded by a flood embankment.

The catchment area of the lake consists mainly of agricultural land (arable land and meadows), which covers 90.5%. Forests account for 6.5% of the area and occur only in the north-western part of the lake. Small areas are occupied by the buildings of the villages Januszewice, Słupia, Sapowice and Strykowo. The reservoir is heavily loaded with recreational activity. On the western shore of the lake there are campsites, a holiday center and recreational houses. At the northern end, there is a bathing area, a camping site and a campsite. The catchment is dominated by soils made of boulder clays and light loamy sands, in the south-western part of the catchment, the top layer of soil is heavily anthropogenically transformed. Directly along the lake, there are peat and peat-muck soils of low bogs occurring within glacial channels (Przybyła et al., 1996).

The morphometric characteristics of both studied lakes are given in Table 1. Lake Niepruszewskie is a source of water for two semi-permanent sprinkler systems: Niepruszewo-Otusz (1004 ha) and the Zborowo-Więckowice sprinkler (236 ha). Water intakes are located in Cieśle and Zborów. Water from the Strykowskie Lake can be used for irrigation of three sprinklers: Jeziorki (231 ha), Sapowice (416 ha) and Strykowo (272 ha) (Table 2). During the research period, i.e. in the years 2009–2016, various precipitation conditions occurred (Table 3). Precipitation totals during the vegetation period (summer half-year) ranged from 266 mm to 462 mm. The average rainfall in the eight-year period under study was 366 mm and was higher by 51 mm (15%) than the multi-year average of 330 mm (Table 4). Greater variability of precipitation occurred in the analyzed period in the months of April and May as well as August and September.

Assesment of water quality

In 2009, as in 1999 (Zbierska and Ławniczak, 2001), the quality of water in Lake Niepruszewskie, determined according to chemical and biological indicators, was in Class III, however, due to the high faecal coli form test, it was generally rated as out of class. In 2016, the sanitary condition of the water improved and the water quality corresponded to Class III. Also most of the chemical indices also slightly improved. The water pH measured in 2016 in Niepruszewskie Lake ranged from 7.6 to 7.9. The results of the assessment of water quality in Lakes Niepruszewskie

Table 1. Characteristics of morphometric parameters of the Niepruszewskie Lake and Strykowskie Lake

Lake	Area (ha)	Volume (thous. m^3)	Mean depth (m)	Max. depth (m)	Max. length (m)	Max. width (m)	Bank line length (m)	Bank line development
Niepruszewskie	242.3	7 578.3	3.1	5.2	4 900	700	11 100	2.01
Strykowskie	305.3	13 637.4	4.5	7.7	8 440	720	19 550	3.16

Table 2. Available water of the studied lakes and the area covered by sprinkler systems

Specification	Unit	Niepruszewskie Lake	Strykowskie Lake
Available water	mln m^3	3.9	4.3
Irrigation through sprinklers	ha	1004 in Niepruszewo-Otusz 236 in Zborowo-Więckowice	231(Jeziorki) 416 (Sapowice) 272 (Strykowo)
Total area covered by rain showers	ha	1240	919

Table 3. Monthly sums of atmospheric precipitation in the Poznan Lake District

Growing season	April	May	June	July	August	September
Monthly precipitation sums in the research period 2009–2016 (mm)						
2009	20.1	86.2	110.3	85.7	23.8	31.8
2010	27.1	110.5	16.8	80.7	153.4	73.8
2011	10.7	10.9	51.6	183.4	48.5	25.1
2012	22.9	59.9	112.3	152.2	38.9	32.5
2013	15.7	87.4	121.4	44.9	35.8	71.6
2014	64.0	87.1	37.6	90.9	44.5	57.1
2015	28.9	25.9	86.1	89.4	13.5	21.1
2016	46.2	33.7	81.8	127.5	41.7	4.3
Minimum (mm)	10.7	10.9	16.8	45.0	13.5	4.3
Maximum (mm)	64.0	110.5	121.4	183.4	153.4	73.8
Mean (mm)	29.5	62.7	77.2	106.8	50.0	39.7
Median (mm)	25.0	73.1	84.0	90.2	40.3	32.2
Standard deviation (mm)	17.5	35.7	38.3	44.5	43.3	25.1
Variability coefficient (%)	59.5	56.9	49.6	41.6	86.7	63.3
Monthly precipitation sums in the years 1981–2020						
Minimum (mm)	1.3	9.7	3.4	10.8	7.0	4.3
Maximum (mm)	81.5	110.5	122.7	200.2	165.9	112.7
Mean (mm)	30.2	48.8	58.5	81.4	55.9	40.3
Median (mm)	28.9	49.1	55.3	76.9	51.2	33.4
Standard deviation (mm)	16.4	25.3	33.4	51.1	33.0	23.8
Variability coefficient (%)	54.3	51.8	57.2	62.7	59.1	59.1

Table 4. Comparison of the sum of precipitation in the Poznan Lake District during the growing season (from April 1 to September 30) in the study years (2009–2016) with the long-term standard (1981–2020)

Parameter	2009–2016	1981–2020
Minimum (mm)	266	135
Maximum (mm)	462	462
Mean (mm)	366	315
Median (mm)	367	330
Standard deviation (mm)	60	85
Variability coefficient (%)	16	27

and Strykowskie in 2009 and 2016 are presented in Table 5. Compared to the results of earlier studies of the State Inspectorate for Environmental Protection, carried out in 1994 (Pułyk and Tybiszewska, 1996), the oxygen conditions and the water transparency using Secchi disc, the content of phosphorus and sestone dry matter and the faecal coli form test increased, while the BOD5 and nitrogen and chlorophyll content decreased.

Salinity is an increasingly important water quality measure, not only in greenhouses or polytunnels, but also in typical field crops. This is related to the water-saving drip irrigation used more and more often for irrigation of field crops. An easily determinable indicator of water salinity, convenient for use in quick, mass field tests, is electrical conductivity. This method of determining the water purity class has been used for a long time, e.g. in the USA, where water is divided into classes depending on conductivity. The sum of the total salt content in the waters of the Niepruszewskie and Strykowskie Lakes in 2009–2016 (Table 5) ranged on average from 1124 to 1651 mg dm^{-3}. The highest salt content was found in the waters collected in 2009 in both lakes (on average about 1663 mg dm^{-3}). According to (Thorne and Peterson, 2010), the salt content in the range of 1500–2500 mg dm^{-3} corresponds to the C4 Class and indicates water with high salinity. Such water can be used for irrigation only in certain specific conditions, i.e. for irrigation of plants resistant to salinity and only on soils with very high permeability, with intensive washing ensured. Such salt content in the waters of the studied lakes was confirmed by the results of conductivity analyses, which also corresponded to the C4 Class in this period

Table 5. Evaluation of water quality in Lakes Niepruszewskie and Strykowskie in 2009 and 2016

Parameter	Sampling time and place	2009		2016	
		Mean value/quality class		Mean value/quality class	
		N	S	N	S
Soluble oxygen (mg O_2 dm^{-3})	SU/AL	9.54/C1	3.83/C1	4.6/C1	0.25/C3
Biological oxygen demand (mg O_2 dm^{-3})	SU/SL	6.8/C3	4.8/C3	3.6/C2	3.4/C2
Total ortophosphates (mg P dm^{-3})	SP/SL	0.01/C1	0.01/C1	0.02/C2	0.02/C1
Total phosphorus (mg P dm^{-3})	SP+SU/SL	0.03/C3	0.06/C3	0.187/C3	0.054/C1
Nitrogen (N-NH_4 + N-NO_3) (mg N dm^{-3})	SP/SL	4.4/C4	3.3/C4	3.294/C4	2.3/C4
Salt content[a] (mg dcm^{-3})	SP/AL	1575/C4	1651/C4	1184/C3	1124/C3
Conductivity[a] (10 mS)	SP/AL	2.68/C4	2.95/C4	1.76/C3	1.15/C3
Electrolytic conductivity (µS cm^{-1})	SP/AL	766/C4	683/C4	668/C4	616/C4
Chlorophyll a (mg m^{-3})	SP+SU/SL	34.86/C4	53.21/C4	55.64/C4	41.42/C4
Dry matter of seston (mg m^{-3})	SP+SU/SL	46.3/C4	19.7/C4	21.08/C4	19.7/C4
Water transparency using Secchi disc (m)	SP+SU	0.96/C4	0.98/C4	0.89/C4	1.25/C4
Score for total water quality class	-	3.11	3.11	3.11	3
Total water quality class	-	III	III	III	III
Faecal coli form test	SP+SU/SL+AL	>0.01/C4[b]	0.09/C3	0.01/C4	0.02/C3

Note: N – Niepruszewskie Lake; S – Strykowskie Lake; SU – summer; AL – above bottom layer; SL – surface layer; SP – spring; [a] – according to Thorne and Peterson (2010); C – water quality (purity) class; [b] – out of classes.

(Table 5). Water with a salt content in a smaller range (500–1500 mg·dm^{-3}) was determined in 2016, which is considered to be of medium salinity (Class C3). This water should be used to irrigate plants resistant to salinity, regularly washed, in soils with medium or high permeability.

The water of Lake Strykowskie over the years from 2009 to 2016 maintained the parameters of Class III and IV purity, with a significant decrease in the value of some indicators, e.g. soluble oxygen. This resulted in a decrease in the purity class of the lake in this parameter (Table 5). On the other hand, the values of some parameters such as BOD5 and total phosphorus, allowed for an increase in the purity class of the lake's waters. The pH of the water of Strykowskie Lake was in the range of pH 7.9–8.3. Comparing the results of the current analyzes to the earlier studies from the 1980s, it should be stated that for many years the lake has been maintaining the III Class of cleanliness, despite the assumed I Class. In this study, a significant reduction in soluble oxygen was noted, as well as a decrease in BOD5. On the other hand, the level of nitrogen increased and the sanitary condition of the water clearly deteriorated (then the faecal coli form test corresponded to Class I or II, now - Class III). Comparison of other parameters cannot be made due to the change in the methodology of lake water quality assessment introduced in the monitoring.

The studied water reservoirs were characterized by good (Niepruszewskie Lake — 56%) and poor oxygen conditions (Strykowskie Lake) in spring and summer. The high level of nutrients, chlorophyll and seston dry matter, as well as the low water transparency using Secchi disc, indicate the progressing eutrophication of both lakes. In order to effectively protect the quality of surface waters and achieve further improvement in their parameters, it is necessary to intensify activities aimed at organizing wastewater management in the direct catchment areas of these lakes, in particular construction of sewage systems and sewage treatment plants for the towns of Niepruszewo, Kalwy and Cieśle, and dissemination of sewage disposal from all septic tanks to treatment plant. On arable land located near lakes, it is advisable to change the sowing structure (in particular, giving up maize cultivation and introducing winter and perennial plants) as well as control and rationalization of fertilization (dividing doses, slow-acting fertilizers, etc.).

The parameters of the catchment area in which the Niepruszewskie and Strykowskie Lakes are located (72% dominance of arable land and 12% low forest cover, and insufficient sewage treatment) indicate a potentially high threat to waters from point and area pollution. The water quality in Lake Niepruszewskie in 2009 was unclassified due to the high values obtained in coli form test. In 2016, however, it corresponded to Class III, which disqualifies not only the recreational usefulness of this reservoir, but above all its role as a source of water for agricultural irrigation. In Lake Strykowskie, the water maintained Class III purity. Compared to earlier studies carried out by the State Inspectorate for Environmental Protection in Poznan in 1994, the amount of BOD5 and the content of mineral nitrogen and chlorophyll decreased in Lake Niepruszewskie, as well as oxygen conditions, water transparency using Secchi disc, phosphorus levels and coliform titre also deteriorated. Compared to the research carried out by the Environmental Research and Control Center in 1982, the content of phosphorus and the amount of BOD5 in Lake Strykowskie decreased, while the sanitary condition, the level of mineral nitrogen and oxygen conditions deteriorated.

Table 6 summarizes the characteristics of phytoplankton (PMPL) and phytobenthos (MMDI). It was found that both the value of the PMPL index and the MMDI index were at a similar level in the case of both studied lakes. It is known that the composition, density and biomass of phytoplankton is variable and dependent on abiotic (physical and chemical) and biotic factors, such as zooplankton, fish or birds associated with the aquatic environment (Amirowicz et al., 2000; Gwiazda et al., 2010). The variability is also closely related to seasonal changes and the cycles of C, N, P and other chemical elements. An important factor modifying the physico-chemical parameters of water, having an indirect effect on phytoplankton, is the environment of a given reservoir and the way it is managed (Wilk-Woźniak et al., 2016). Any changes in environmental factors are reflected in the dynamics, density, biomass and groups of dominant phytoplankton communities of a water body (Godlewska et al., 2003; Strzesak, 2014; Wilk-Woźniak, 1996, 2000; Wilk-Woźniak and Marshall, 2009).

Higher values of dissolved oxygen were found in the waters of Lake Niepruszewskie compared to Lake Strykowskie (Table 7). In studies of waters conducted in earlier years (2004–2009), dissolved oxygen values of 8.66 and 8.73 mg O_2 dm^{-3} were found for Lakes Niepruszewskie and Strykowskie, respectively (Przybyła et al., 2011). However, for comparison, even earlier studies conducted in period 1989–1994, found dissolved oxygen values of 9.4 and 9.6 mg O_2 dm^{-3} for Lakes Niepruszewskie and Strykowskie, respectively (Przybyła et al., 1996). The study of the water transparency of both lakes carried out in 2016 showed that a higher value of this indicator occurred in Lake Strykowskie than in Lake Niepruszewskie.

A higher content of nutrients, both nitrogen and phosphorus, occurred in the waters of Lake Niepruszewskie than in Lake Strykowskie (Table 8). This is mainly due to the fact, that the water quality in studied lakes is mainly determined by surface runoff from the surrounding agricultural areas. The lack of natural protective barriers in the form of forests and wooded areas around Lake Niepruszewskie results in water with a higher content of nutrient indicators, such as nitrogen and phosphorus. In contrast, Lake Strykowskie

Table 6. Characteristics of phytoplankton and phytobenthos in the studied lakes (average values in period 2009–2016)

Specification	Phytoplankton (PMPL)		Phytobenthos (MMDI)	
	Niepruszewskie Lake	StrykowskieLake	Niepruszewskie Lake	Strykowskie Lake
Maximum value	3.68	3.31	1.23	0.899
Minimum value	1.94	2.18	0.81	0.530
Range	1.74	1.13	0.42	0.369

Table 7. Characteristics of transparency and dissolved oxygen content in the analyzed lakes (average values from the period 2009–2016)

Specification	Transparency (m)		Dissolved oxygen (mg O_2 dm^{-3})	
	Niepruszewskie Lake	Strykowskie Lake	Niepruszewskie Lake	Strykowskie Lake
Maximum value	1.00	1.25	9.54	3.83
Minimum value	0.89	0.80	4.60	0.25
Range	0.11	0.45	4.94	3.58
Avarage value	0.95	1.08	7.08	1.44

is mostly surrounded by forests than Lake Niepruszewskie (Przybyła et al., 2006, 2011).

Higher values of electrolytic conductivity were found in the waters of Lake Niepruszewskie than in Lake Strykowskie (Table 9). In comparison, in studies conducted in earlier years (2004–2009), electrolytic conductivities of 708.72 and 649.46 µS cm^{-1} were found for Lakes Niepruszewskie and Strykowskie, respectively (Przybyła et al., 2011).

Tables 10 compares the average contents of biogenic components (phosphorus, nitrogen) in the waters of the studied lakes with the results obtained in previous studies (Przybyła et al., 1996, 2006, 2011). In 2016, an increase in nitrogen content and a decrease in phosphorus content were observed compared to previous studies. In all study periods, lower nitrogen contents were found in the waters of Lake Strykowskie compared to Lake Niepruszewskie.

During the analyzed period (1989–2016), a decreasing trend in phosphorus concentrations was observed in the waters of both studied reservoirs (Table 10). This is confirmed by the detailed findings of (Przybyła et al., 2006) regarding the waters of 20 lakes of the Poznan Lake District (Przybyła et al., 2011).

CONLUSIONS

The paper evaluates the quality of water used for sprinkler irigation from two lakes located in the Poznan Lake District – Niepruszewskie and Strykowskie. Based on the conducted research, it appears that in the Lake Niepruszewskie, the oxygen conditions, the water transparency, the content of phosphorus, the sestone dry matter and the coliform titre increased, but the biological oxygen demand, and nitrogen and chlorophyll content decreased. In turn, in the case of Lake Strykowskie, the content of phosphorus and biological oxygen demand decreased, but the sanitary condition, the level of mineral nitrogen and oxygen conditions deteriorated. The results obtained were compared with the results of previous studies carried out in the former Department of Agricultural and Forestry Land Reclamation, now the Department of

Table 8. Characteristics of the content of total nitrogen and total phosphorus in the analyzed lakes (average values from the period 2009–2016)

Specification	Total nitrogen (mg N dm^{-3})		Total phosphorus (mg P dm^{-3})	
	Niepruszewskie Lake	Strykowskie Lake	Niepruszewskie Lake	Strykowskie Lake
Maximum value	4.400	3.800	0.187	0.074
Minimum value	3.294	2.300	0.031	0.054
Range	1.106	1.500	0.156	0.020
Avarage value	4.021	3.116	0.090	0.063

Table 9. Water eletrolytic conductivity at 20°C (µS cm^{-1}) in the studied lakes (average values from the period 2009–2016)

Specification	Eletrolytic conductivity (µS cm^{-1})	
	Niepruszewskie Lake	Strykowskie Lake
Maximum value	765.75	683.00
Minimum value	668.00	616.00
Range	97.75	67.00
Avarage value	715.25	647.67

Table 10. Comparison of the average content of total nitrogen and total phosphorus during the growing season in the waters of the analyzed lakes with the results obtained in previous studies

Period	Total nitrogen (mg N dm^{-3})		Total phosphorus (mg P dm^{-3})	
	Niepruszewskie Lake	Strykowskie Lake	Niepruszewskie Lake	Strykowskie Lake
1989–1994 (Przybyła et al., 1996)	1.85	1.35	0.20	0.40
1999–2006 (Przybyła et al., 2006)	1.77	0.88	0.26	0.13
2004–2009 (Przybyła et al., 2011)	6.71	3.53	0.12	0.06
2009–2016	4.02	3.12	0.09	0.06

Land Reclamation, Environmental Formation and Spatial Management at the Poznan University of Life Sciences (Przybyła et al., 1996, 2006, 2011). The source of pollution of the waters of the two studied lakes is most often outflows from sewerage systems receiving domestic sewage and these are point source pollution. On the other hand, the sources of pollution of a spatial nature are precipitation and surface runoff from the catchment areas of these lakes, which are mainly used as agricultural land. The reduction of mineral fertilization in recent years has reduced the degradation of the lakes and allowed the water quality to remain in Class III of purity. The results of the research showed that the quality of water in the studied lakes is gradually improving. However, in order for these waters to be used for sprinkler irrigation of the surrounding agricultural crops, it is necessary to constantly monitor the quality of water in both studied lakes.

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