Oceanological and Hydrobiological Studies

International Journal of Oceanography and Hydrobiology

Volume 49, No. 4, December 2020
pages (345-353)

ISSN 1730-413X
eISSN 1897-3191

Influence of land development on the ecological status of small water bodies

by

Anna Dudzińska*, Barbara Szpakowska, Maria Pajchrowska

DOI: **10.1515/ohs-2020-0030**
Category: **Original research paper**
Received: **April 17, 2020**
Accepted: **June 8, 2020**

Department of Landscape Architecture, Poznań University of Life Science, ul. Dąbrowskiego 159, 60-594 Poznań, Poland

Abstract

Small water bodies play a specific role in the landscape, as they increase the mosaic pattern of a given area, retain water and affect hydrological regime in adjacent soils. These water bodies are the most important in landscapes that have been largely transformed by man, such as agricultural and urban landscapes. The author of this study assessed the ecological status of small water bodies using the Q index and determined the impact of the development of adjacent areas on their ecological status. The analysis of the Q index referring to water bodies showed that its values changed considerably not only during the whole study period but also during one year (from 1.74 to 4.28). The land use analysis in the designated buffer zones stretching within 500 m and 1000 m from the water bodies showed that arable land occupied the largest area. This fact determines the ecological status of these water bodies. Ecotones that develop around ponds can function as biogeochemical barriers reducing pollution in the area. A total of 116 species of vascular plants were identified in the water bodies under study. Herbaceous plants constituted the largest group – 87 species. Trees and shrubs were represented by 16 species and macrophytes by 16 taxa.

Key words: small water bodies, land use, ecological status of waters, Q index

* Corresponding author: anna.dudzinska@up.poznan.pl

DE GRUYTER

online at www.oandhs.ug.edu.pl

Introduction

Water bodies are an important element of any landscape. They differ in size, depth, genesis, the ecological status of water, water supply and development. Some of them are referred to as small water bodies when their area does not exceed 1 ha and their depth does not exceed 2–3 m (Biggs et al. 2005; Drwal et al. 1985). It is estimated that there are 277 400 000 ponds of less than 1 ha and 24 120 000 water bodies ranging from 1 to 10 ha, thus representing over 90% of the 304 million standing waterbodies worldwide (Downing et al. 2006). In terms of their genesis, they are divided into anthropogenic water bodies, e.g. clay and peat pits, and natural water bodies, e.g. glacial and meteorite ponds (Gołdyn et al. 2012). Water bodies are also classified according to their hydrological state into those that are always filled with water, those that are periodically filled with water and ponds without water covered with vegetation (Kędziora 2012). The number of small water bodies changes significantly over time (Paczuska et al. 1997; Markuszewska 2002; Bosiacka et al. 2004). On the one hand, they are backfilled due to the increased demand for agricultural or construction land (Mioduszewski 2008). On the other hand, they are created for economic purposes, e.g. fish farms, and ornamental and recreational purposes, e.g. ponds near palaces. At present, the rate of formation of small water bodies is much slower than the rate of their degradation (Kędziora et al. 2005; Ożgo 2010). According to Markuszewska (2002), 775 out of 1130 ponds disappeared from the south-eastern Wielkopolska region (Krotoszyn Land) in the last two decades of the 20th century. According to Hildebrandt-Radke et al. (2011), the number of water bodies with an area below 1 ha has decreased in the central Wielkopolska region by 60% over the last 200 years. Dudzińska et al. (2016) compared the number of small water bodies in the commune of Rokietnica near Poznań in the 19th and 21st centuries. The number decreased by 15.9%, and the largest decrease was recorded in agricultural areas.

Small water bodies undergo greater dynamic changes over time than large water bodies, as the latter are permanent and stable landscape elements (Kochanowska et al. 1997; Céréghino et al. 2016). Small water bodies are less resistant to degradation not only because they are not very deep and do not retain a large volume of water, but also because they are subject to more frequent sediment resuspension due to water rippling. According to the theory of alternative stable states, shallow lakes can function stably in a system where macrophytes (pure water) or phytoplankton (turbid water) dominate (Scheffer et al. 1993; Peckham et al. 2006; Zębek et al. 2017). Small water bodies relatively quickly become silted and overgrown with vegetation and consequently disappear. These processes are caused both by natural (ecological succession and periodic rainfall deficiency) and anthropogenic factors (drainage works, cutting down trees and shrubs around water bodies, burning of shore vegetation, sewage discharge and waste storage; Céréghino et al. 2008; Dulić et al. 2014). Ponds have become more protected, particularly in the Mediterranean regions of Europe, following the recognition of Mediterranean temporary ponds as a priority in the EU (Céréghino et al. 2008).

Research on phytoplankton and macrophytes resulted in the development of a number of coefficients indicating the ecological status of water bodies. They provide information about the characteristics of the aquatic environment on the basis of various biological elements (Hutorowicz 2013). The Water Framework Directive (2000) uses analyses of biological elements, e.g. phytoplankton and macrophytes, to assess the condition of water. Phytoplankton is critical to the food chain of ponds as it provides food for many microscopic animals that in turn are eaten by fish fry or larger invertebrates. Occasionally, planktonic algae can form a large floating mass and bloom to significant levels, which may necessitate the use of control methods (Celewicz-Gołdyn et al. 2008; Çelekli et al. 2014).

The following phytoplankton characteristics are examined in Poland: the total biomass of phytoplankton, the biomass of cyanobacteria in summer, the concentration of chlorophyll *a* (Hutorowicz 2013) and species composition (Picińska-Fałtynowicz et al. 2012). Various methods have been developed. Some methods are based on the biomass or the count of phytoplankton, while others analyze its structure (dominant and indicator species). Following the Water Framework Directive, the member states developed methods to assess the status of surface water. For example, these are a phytoplankton multimetric index in Germany (Phyto-Seen-Index-PSI; Hutorowicz 2013), the phytoplankton community indicator Q based on the concept of functional groups in Hungary (Padisák et al. 2006 and the phytoplankton multimetric index for Polish lakes (PMPL; Hutorowicz et al. 2014). When using hydromacrophytes for assessing the quality of lentic water bodies in Poland, the following are distinguished: macrophyte assessment and classification of the ecological status of lakes (Rejewski's method) – Ecological State Macrophyte Index ESMI (Ciecierska et al. 2013) and macrophyte identification keys (Szoszkiewicz et al. 2010).

The study aimed to assess the ecological status of small water bodies using the Q-index calculated on the basis of the biomass of phytoplankton functional groups and to determine the impact of the development of areas adjacent to water bodies on their ecological status.

Materials and methods

The study was conducted at monthly intervals between 2013 and 2015. Four water bodies located in the northwest of the commune of Dopiewo, about 20 km west of Poznań, were analyzed. Two water bodies, i.e. No. 1 and 2, are located in the village of Więckowice, water body No. 3 is located in Dopiewo, water body No. 4 – in Dopiewiec.

Water body No. 1 (52°39′50″N; 16°38′25″E) is of natural origin. Its maximum depth is small, i.e. 1.2 m. Its area does not exceed 500 m^2, its volume does not exceed 400 m^3. The water body is located in a large but neglected park near a palace, near trunk road 307 (Poznań–Buk) and a pig farm. The catchment area of water body No. 1 covers about 3 ha.

Water body No. 2 (52°23′3″N; 16°38′46″E) is located next to the main road crossing the village of Więckowice. It is one of the largest water bodies analyzed in the study. Its area is nearly 2000 m^2, its volume – about 1700 m^3, its maximum depth is 1.7 m, the catchment area – 54.5 ha, Schindler's coefficient – 319. The water body is a fire protection pond used for recreational purposes. In late June 2013, bottom sediments were removed from the pond.

Water body No. 3 (52°21′39″N; 16°40′23″E) was the largest pond (5812 m^2) analyzed in the study. Its catchment area is about 111 ha, the maximum depth is 2 m and the water volume is 7747.96 m^3. It is a flow-through water body with the inflow in the northwest and the outflow in the southeast. It is about 150 m long and about 50 m wide. Similarly to water body No. 2, it is a fire protection pond used for fishing and recreational purposes. It has a regular shape and is reinforced with fascines. The shores have been developed for recreational purposes. A volunteer fire station is located on the southeastern shore. Macrophytes are removed from the pond every autumn.

Water body No. 4 (52º22′21″N; 16º41′52″E) is located within arable fields, not far from a mixed forest. It is of natural origin. Similarly to water body No. 1, it is one of the shallowest water bodies analyzed in the study (0.9 m). Its area does not exceed 300 m^2, its volume slightly exceeds 150 m^3 and the catchment area is about 4.34 ha. The water body and its surroundings are a refuge for wild boars. Every year their breeding grounds are found in the zone around the shores of the pond.

Q index

The ecological Q index was calculated to assess the ecological status of waters on the basis of functional groups. Phytoplankton was analyzed for species composition, abundance and biomass using cylindrical 9 or 14 cm^3 planktonic chambers and MOD-2 reverse microscopy (PZO) and CKX41 (Olympus). A CKX-41 microscope with image analysis was used for precise measurements and photographic documentation. Phytoplankton species identified in water were assigned to functional groups. The biomass of each functional group was referred to the total biomass of phytoplankton by determining its contribution to the total biomass. Next, using the method presented by Padisák et al. (2006), a value of the F index (0–5) was assigned to each of these groups. Following the guidelines in the study, water bodies No. 1 and No. 4 were assigned to type 6, whereas water bodies No. 2 and No. 3 were assigned to type 5. The following formula was used to calculate the Q index value:

$$Q = \sum_{i=1}^{n} p_i F_i$$

$p = n_i/N_i$: n_i – biomass of functional group i, N_i – total biomass of phytoplankton

F_i = lake type indicator (Padisák et al. 2006)

The ecological status of the water bodies was calculated by assigning the Q index value to the ranges given in Table 1.

The ArcMap program was used to determine the catchment areas of individual water bodies and land development within 500 and 1000 m around the water bodies. The shortest distances from potential sources of pollution were calculated using the GIS analysis,

Table 1

Classification of the ecological status of water based on the Q index

Ecological status	Q index value
Very good	4.0–5.0
Good	3.0–4.0
Medium	2.0–3.0
Poor	1.0–2.0
Bad	0–1.0

which is increasingly used in environmental research (Aynur et al. 2018; Pham et al. 2016).

Results and discussion

Ecological status of the water bodies based on the Q index

The Q index is based on the biomass of phytoplankton functional groups. These organisms are considered good indicators of fertility and purity of water because they quickly respond to changing environmental conditions (Wilk-Woźniak 2016). The Q index value varied considerably from 1.74 to 4.28. It showed that in 2013 the ecological status of water body No. 1 was very good, but in 2014 and 2015 it was good. The ecological status of water body No. 3 was medium throughout the study period. The ecological status of water body No. 2 was gradually improving – it was poor in 2013 and medium in 2014 and 2015. A similar trend was observed in water body No. 4, as its ecological status was poor in 2013, but changed by two levels and was good in the subsequent years (Fig. 1).

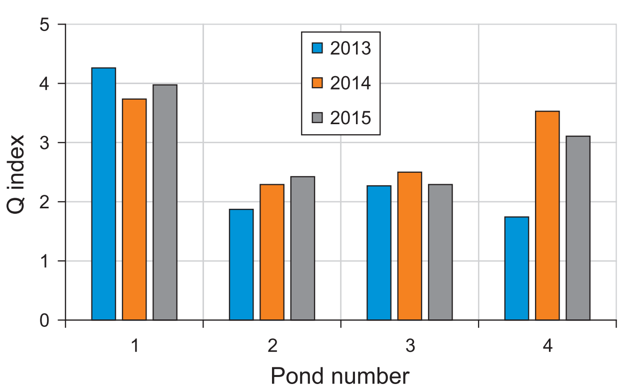

Figure 1

Changes in the Q index for water bodies No. 1–4 between 2013 and 2015

The analysis of the Q index showed that its values changed considerably not only during the whole study period, but also during one year.

Between 2013 and 2015, the ecological status of water body No. 1 was very good in the summer, which was manifested by high values of the Q index. In the first year of the study, it dropped to 3.4 in October, but increased to almost 5 in November. In November 2015, the Q index value was lower, but the ecological status was still very good, whereas as in 2014 the ecological status deteriorated and was only good (Fig. 2).

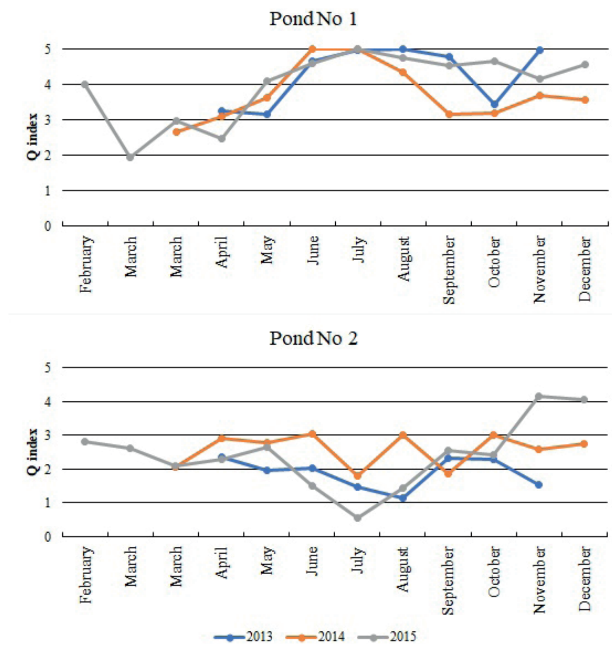

Figure 2

Changes in the Q index for water bodies No. 1 and 2 between 2013 and 2015

The value of the Q index for water body No. 2 fluctuated considerably throughout the study period. In the first year, the highest value of the Q index was recorded in September and the ecological status of the water body was medium. In the second year, the parameter (about 3) had four peaks (in April, June, August, and October) and the ecological status varied from medium to good. In February, May and September 2015, the Q index value indicated the medium ecological status of the water body, whereas in November the status was very good. In July 2015, on the other hand, the Q index had the lowest value, which indicated that the ecological status of the water body was bad (Fig. 2).

The highest value of the Q index for water body No. 3 was recorded in June 2013. It indicated that the ecological status of the water body was good. In the remaining months of 2013, the ecological status was medium or poor. In 2014, the status was medium until September, good in October and November, and deteriorated to the poor level in December. In 2015, the lowest value of the Q index was recorded in August (0.9), followed by a gradual increase and the highest value (4.05) in December, which indicated that the ecological status of the water body was very good (Fig. 3).

The value of the Q index for water body No. 4 fluctuated considerably in all seasons of the year throughout the study period. In spring, it varied from

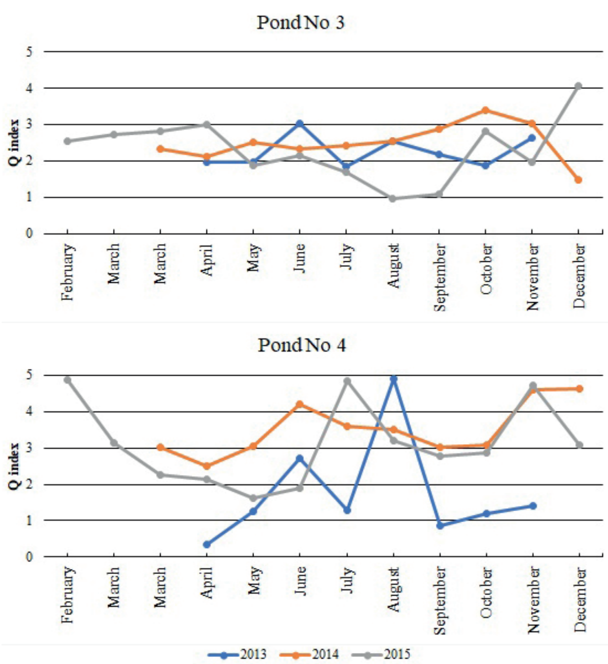

Figure 3

Changes in the Q index for water bodies No. 3 and 4 between 2013 and 2015

0.3 (bad) to 3.1 (good), in summer – from 1.3 (poor) to 4.9 (very good), in autumn – from 0.9 (bad) to 4.7 (very good), and in winter – from 3.1 (good) to 4.9 (very good) (Fig. 3).

Development of the catchment areas

The catchment area, which includes different types of land use around the ponds, can be one of the most important factors affecting the functioning of small water bodies. The catchment areas of individual water bodies were determined and the land cover in the buffer zones stretching within 500 m and 1000 m from the water bodies was analyzed to assess the impact of land development on the ecological status of these water bodies.

There are three types of catchment cover in the landscape with different barrier properties – wetlands and swamps are the strongest barriers; forests, meadows and pastures are moderate barriers, whereas arable land and urban areas are "zero" barriers (Mozgawa 1993). The catchment area, which is covered in 40% by wetlands and water bodies, retains over 90% of agricultural contamination (Mioduszewski 1993). Most chemicals, including nutrients, migrate into the aquatic environment with runoff from the catchment. This phenomenon is closely related to climatic conditions, especially precipitation and seasons. In addition, the flow of nutrients can be modified by topography, soil type and the intensity of catchment development (Solarska et al. 1993). Unlike lakes and rivers, ponds have a low capacity for dilution or buffering of nutrient inflow, which is why poor-quality ponds are often degraded to an extreme extent rarely observed in larger waters (Biggs et al. 2005).

The development of the catchment area of water body No. 1 did not change significantly during the study period. Most of the catchment area is occupied by gardens, roads, lawns (40.5%) and a park (38.5%). As far as the catchment area of water body No. 2 is concerned, it is occupied by arable fields in the east and by single-family houses and outbuildings in the north and west. Arable land and wasteland cover 94.3% of the catchment area, grasslands – 4.2%, buildings – 1.5%. Most of the catchment area of water body No. 3 is covered by arable land (87.6%), whereas buildings and paved roads occupy about 12%. The catchment area of water body No. 4 covers 4.34 ha, whereas the area of the water body is 256 m^2. The catchment area is mostly occupied by arable land, where cereals were grown in 2013 and maize was grown in 2014 and 2015. Information on the effects of land use on farmland ponds is very scarce. As farmland ponds are different from larger ponds and lakes, they are expected to be affected by land use via other mechanisms operating at different spatial scales (Declerck et al. 2006).

The effect of land use on the designated buffer zones

The analysis of land use in the buffer zones showed that arable land occupied the largest area in the buffer zone stretching over a distance of 500 m from the water bodies. The contribution of arable land ranged from 52.3% (water body No. 3) to 78% (water body No. 2; Fig. 4). Farmland also occupies the largest part of the Polish territory, surrounding and penetrating other ecosystems. The soil in the catchment area dominated by farmland is largely depleted of nutrients (Górniak 2006). Crop agriculture, especially row crop farming with frequent tillage, leads to high rates of nutrient and sediment export. This may ultimately results in increased nutrient loads, which adversely affect the cover and richness of aquatic vegetation in favor of phytoplankton. Therefore, it is very important to consciously activate and stimulate the effectiveness of environmental self-cleaning mechanisms in the agricultural landscape through adequate impact on landscape components such as trees and vegetation at the shores of water bodies. The fact that 29% of the buffer zone around water body No. 4 is covered with forests may have contributed to

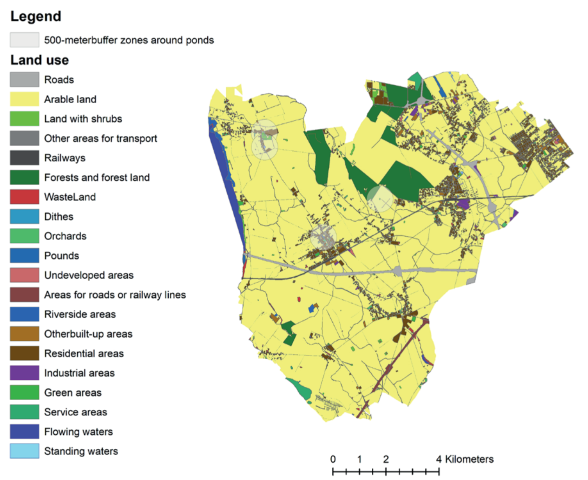

Figure 4

Land use types in 500 m buffer zones around the water bodies

the improvement of the ecological status of water in this pond from poor to good during the three years of the research. Furthermore, buffer zones with a mosaic pattern and various species of trees, shrubs and grasses are six times more effective in reducing the phosphorus flow into water bodies than catchments characterized by homogeneous vegetation. The mechanisms responsible for the protective role of biogeochemical barriers involve various processes such as sedimentation, sorption, denitrification and assimilation, which require the coexistence of plants and microorganisms in aquatic ecosystems (Łaskawiec 2015).

The proportion of houses and roads in all buffer zones is significant. There are also orchards around

Table 2

The number of taxa of vascular plants in water bodies No. 1–4 between 2013 and 2015

Water body	Plants	2013	2014	2015
No. 1	trees and shrubs	8	8	8
	herbaceous plants	6	6	9
	macrophytes	1	1	1
No. 2	trees and shrubs	3	3	3
	herbaceous plants	5	9	18
	macrophytes	3	5	2
No. 3	trees and shrubs	1	1	1
	herbaceous plants	6	10	22
	macrophytes	2	2	2
No. 4	trees and shrubs	4	4	3
	herbaceous plants	11	16	14
	macrophytes	7	8	7

water bodies No. 3 and 4, which may affect the ecological status of water in these ponds. A total of 116 species of vascular plants were identified in the water bodies under study. Herbaceous plants constituted the largest group – 87 species. Trees and shrubs were represented by 16 species and macrophytes by 16 taxa. The study shows that a 6 m strip of grass and sedges reduces the content of nitrogen in water by 47%, whereas a 20 m zone reduces the content of this element by nearly 100% (Wysocka-Czubaszek et al. 2003). A 20 m wide zone of trees may reduce the amount of nutrients running off the fields by as much as 70–80% (Szpakowska 1999; Andrzejewski et al. 2003). The number of tree and shrub species growing around the water bodies did not change during the study period. The only exception was water body No. 4, where *Crataegus monogyna* was not found in 2015. The number of macrophyte taxa in water bodies No. 1 and 3 was the same, whereas it slightly changed in water bodies No. 2 and 4. Herbaceous plants were always characterized by greater species abundance than macrophytes, trees and shrubs (Table 2). Declerck et al. (2006), who studied 99 small farmland ponds scattered throughout the Belgian territory, revealed significant correlation between land use in the surrounding area and the vegetation complexity. They observed a negative correlation between crops in the immediate vicinity of ponds and the number of plant growth types.

The analysis of land development in the 1000 m buffer zone around the water bodies showed that most of the area was also occupied by arable land (from 61% around water body No. 4 to 85% around water body No. 3). There were industrial buildings withing the 1000 m buffer zone around water bodies No. 1, 3 and 4. They occupied an area of less than 0.03 ha (Fig. 5).

The soils in the commune of Dopiewo can be classified as average. There is no arable land with soils of the most fertile classes, i.e. I and II. The study included analysis of individual classes of soils in the areas around the water bodies. The arable land around water bodies No. 1 and 2 has mostly class IVB soils, which cover areas of 110.2 ha and 117.2 ha, respectively. The arable land around water body No. 3 has class IIIB soils (64.7 ha). Class V soils occur around water body No. 4 (77 ha). The soil classes within the 500 m buffer zones around the water bodies range from IIIA to VI. The quantitative characteristics of watercourses in the landscape, which were obtained by determining the physicochemical properties of soils, constitute the basis for spatial planning aimed at reducing the spatial pollution. Groundwater-gley podzols with a shallow groundwater table as well as low-humus

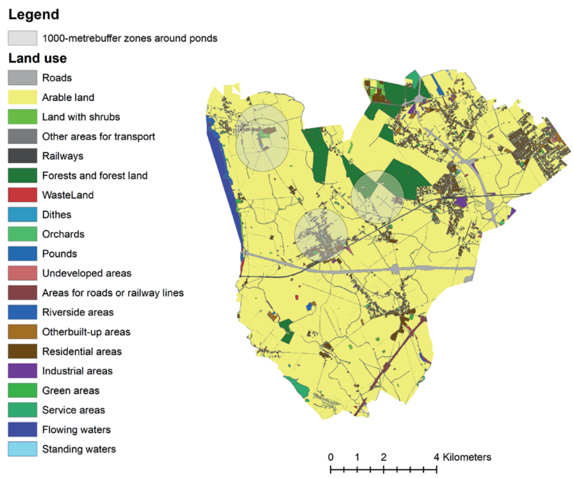

Figure 5

Land use types in 1000 m buffer zones around the water bodies

rusty soils formed from sand may be potential places of accelerated chemical contamination of ground and surface waters, including ponds.

The shortest distances from potential sources of contamination were also calculated for the water bodies under study (Table 3). The vicinity of animal farms, mines, sewage treatment plants, landfills, production plants and roads was taken into consideration. The analysis showed that water body No. 1 was located only about 20 m from a livestock farm. The trophic state of the water body was gradually deteriorating during the three years of the research. This may have been caused by the short distance between the water body and the pig farm. Water bodies No. 1, 2 and 3 are located 26–33 m from the roads. Water body No. 4 is located 243 m from the nearest road. Davies et al. (2007) observed that the small scale of pond catchments combined with their relatively high contribution to the landscape biodiversity provides many opportunities for cost-effective conservation strategies.

Conclusions

The ecological status of the water bodies, determined on the basis of the Q index, considerably varied due to the predominance of arable land within the immediate vicinity of the water bodies, i.e. in the buffer zones stretching within a 500 and 1000 m radius. The Q index has an advantage over the PMPL multimetric index as it is possible to use the former for assessing the ecological status of water bodies in shorter time intervals. The latter uses the total phytoplankton biomass, the concentration of chlorophyll *a* and the biomass of cyanobacteria, which require data from the entire growing season. In addition, it also requires information on the catchment area, which is often difficult to accurately determine for small water bodies.

Areas adjacent to water bodies are important for the functioning of small aquatic ecosystems. As evidenced by various studies, the amount of contaminants reaching the water bodies primarily depends on the type of catchment area (Fiedler et al. 1999; Skierawski 2010; Bedla et al. 2014).

In the agricultural landscape, which dominates in the area under study, the presence of biogeochemical barriers such as meadows or tree stands is particularly important, because they could improve the quality of water in the water bodies. Depending on their nature, they can accelerate or slow down the inflow of mineral and organic matter into water bodies. An adequate landscape structure, which stimulates the intensity of small water circulation, is also important in terms of preventing soil desiccation, which is one of the greatest threats to the agricultural environment in the Wielkopolska region. Therefore, it is very important to preserve small water bodies in good ecological condition. Their evaporation rate is much higher compared to large water bodies. Water, which is normally discharged into the sea as a result of spring runoff, can be locally incorporated into a small water circuit and thus improve the habitat humidity.

Table 3

The shortest distance from facilities that may be potential sources of pollution

No. of water body	Distance from the nearest livestock farm (m)	Distance from the nearest mine (m)	Distance from the nearest sewage treatment plant (m)	Distance from the nearest landfill (m)	Distance from the nearest production plant (m)	Distance from the nearest road (m)
1	20.3	6836	6720	6698	418	32
2	418	7000	6200	6174	931	33
3	4281.5	7040	2497	2538	897	26
4	3779	4596.5	4292	4688	2416	243

References

Andrzejewski, R. & Weigle, A. (2003*). Różnorodność biologiczna Polski*. Narodowa Fundacja Ochrony Środowiska, Warszawa.

Aynur, M., Liming, W. & Fang, Y. (2018). Spatial evaluation of environmental suitability for human settlement of Kashgar, Northwest China. *Fresenius Environmental Bulletin* 27(9): 5899–5907 .

Bedla, D. & Misztal, A. (2014). Zmienność chemizmu wód małych zbiorników wodnych o zróżnicowanej strukturze użytkowania terenów przyległych. *Rocznik Ochrona Środowiska* 16: 421–439.

Biggs, J. Williams, P., Whitfield, M., Nicolet, P. & Weatherby, A. (2005). 15 years of pond assessment in Britain: results and lessons learned from the work of Pond conservations. *Aquatic Conservation: Marine and Freshwater Ecosystems* 15: 1–22. DOI: 10/1002/aqc.745.

Bosiacka, B. & Pieńkowski, P. (2004). Analiza przekształceń oczek wodnych oraz ocena walorów przyrodniczych śródpolnych zbiorników w centralnej części Równiny Nowogardzkiej. *Woda-Środowisko-Obszary Wiejskie. Instytut Melioracji i Użytków Zielonych w Falentach* 4, 2a (11): 335–349.

Çelekli, A. & Öztürk, Kapı M. (2014). Relationship between phytoplankton composition and environmental variables in artificial pond. *Algal Reserch* 5(2014): 37–41 DOI: 10.12657/steciana.018.021.

Celewicz-Gołdyn, S., Kuczyńska-Kippen, N. & Nagengast, B. (2008). Phytoplankton community structure in two types (forestry vs. Field) of small water bodies. *Roczniki Akademii Rolniczej w Poznaniu* CCCLXXXVII, 12 (2008): 23–28.

Céréghino, R., Biggs, J., Oertli, B. & Declerck, S. (2008). The ecology of European ponds: defining the characteristics of a neglected freshwater habitat. *Hydrobiologia* 597: 1–6 DOI: 10.1007/978-90-481-9088-1_1.

Céréghino, R ., Boix, D., Cauchie, H., Martens, K. & Oertli, B. (2014). The ecological role of ponds in a changing world. *Hydrobiologia* 723(2014): 1–6. DOI: 10.1007/s10750-013-1719-y.

Ciecierska, H. & Dynowska, M. (2013). Klasyfikacja jakości wód powierzchniowych. In H. Ciecierska & M. Dynowska (Eds.), *Biologiczne metody oceny stanu środowiska*. *Tom II. Ekosystemy wodne* (pp. 9–37). Uniwersytet Warmińsko-Mazurski w Olsztynie, Wydawnictwo Mantis, Olsztyn.

Davies, B.R., Biggs, J., Wiliams, P.J., Lee, J.T. & Thompson, S. (2007). Comparision of the catchment sizes of rivers, streams, ponds, ditches and lakes: implications for protecting aquatic biodiversity in an agricultural landscape. *Hydrobiologia* 597: 7–17 DOI: 10.1007/s10750-007-9227-6.

Declerck, S. De Bie, T., Ercken, D., Hampel, H., Schrijvers, S. et al. (2006). Ecological characteristics of small farmland ponds: Associations with land use practices at multiple spatial scales. *Biological Conservation* 131(2006): 523–532.

Downing, J.A., Prairie, Y.T., Cole, J.J., Duarte, C.M., Tranvik, L.J. et al. (2006). The global abundance and size distribution of lakes, ponds and impoundments. *Limnology and Oceanography* 51: 2388–2397. DOI: 10.4319/lo.2006.51.5.2388.

Drwal, I. & Lange, W. (1985). Some limnological distinct meshes. The origin and location of pond. *Zesz. Nauk. Wydziału Biologii Nauk Ziem. Geogr.* 14: 68–83.

Dudzińska, A., Szpakowska, B. & Szumigała, P. (2016): Zbiorniki i cieki wodne w krajobrazie rolniczym. *Wieś i Rolnictwo* 2(171): 199–210.

Dulić, Z., Marković, Z., Živić, M., Ćirić, M., Stanković, M. et al. (2014). The response of phytoplankton, zooplankton and macrozoobenthos communities to change water supply from Surface to groundwater in aquaculture ponds. *Ann. Limnol. – Int. J. Lim.* 50(2014): 131–141. DOI: 10.1051/limn/2014005.

Fiedler, M. & Szafrański, Cz. (1999). Variation of ground-water levels in the catchment of the midfield pond located at Gniezno Lakeland. *Rocz. AR Pozn. 310, Melior. Inż.* Środ. 20 (I): 403–412.

Gołdyn, R. & Kędziora, A. (2012). Potrzeba ochrony zbiorników śródpolnych. Fundacja Biblioteka Ekologiczna. Wydział Biologii Uniwersytetu im. Adama Mickiewicza w Poznaniu. Instytut Środowiska Rolniczego i Leśnego Polskiej Akademii Nauk w Poznaniu: 14–24.

Górniak, A. (2006). Lakes in Podlasie Province (NE Poland) – present trophy state and water quality. *Pol. J. Environ. Stud.* 15: 361–364.

Hildebrandt-Radke, I. & Przybycin, J. (2011). Zmiany sieci hydrograficznej i zalesienia a melioracje regionu środkowej Obry (centralna Wielkopolska) w świetle danych historycznych i materiału kartograficznego. *Przegląd Geograficzny. Polska Akademia Nauk* 83(3): 323–342.

Hutorowicz, A. (2013). Ocena stanu ekologicznego jezior z wykorzystaniem fitoplanktonu. In H. Ciecierska & M. Dynowska (Eds.), *Biologiczne metody oceny stanu środowiska. Tom II ekosystemy wodne* (pp. 38–58). Uniwersytet Warmińsko-Mazurski w Olsztynie, Wydawnictwo Mantis, Olsztyn.

Hutorowicz, A. & Pasztelaniec, A. (2014). Phytoplankton metric of ecological status assessment for polish lakes and its performance along nutrient gradients. *Pol. J. Ecol.* 62: 525–542.

Kochanowska, R., Pieńkowski, P. & Wołejko, L. (1997). Śródpolne oczka wodnew *krajobrazie Pomorza Szczecińskiego. Woda jako czynnik warunkujący wielofunkcyjny i zrównoważony rozwój wsi i rolnictwa.* Konferencja Naukowo-Techniczna, Falenty: 230–235.

Łaskawiec, E. (2015) The role of biogeochemical barriers in protecting aquatic ecosystems against pollution in agricultural environment. *Folia Biologica et Oecologica* 11: 9–15. DOI: 10.1515/fobio-2015-0002.

Markuszewska, I. (2002). Śródpolne oczka wodne w rolniczym krajobrazie Ziemi Krotoszyńskiej. *Aura* 6: 14–15.

Mioduszewski, W. (2008). *Małe zbiorniki wodne w obszarach wiejskich*. *Wieś Jutra*. Zakład Zasobów Wodnych, Instytut Melioracji i Użytków Zielonych, Falenty 10(123): 32–34.

Mozgawa, J. (1993). Photointerpretation analysis of landscape structure in lake watersheds of Suwałki Landscape. *Park. Ekol. Pol.* 41: 53-74.

Ożgo, M. (2010): Rola małych zbiorników wodnych w ochronie bioróżnorodności. *Parki Narodowe i Rezerwaty Przyrody* 29(3): 117–124.

Paczuska, B. & Paczuski, R. (1997). Problem zanikania naturalnych zbiorników śródpolnych i śródleśnych na południowym skraju Wysoczyzny Świeckiej. In L. Burchard (Ed.), *Teoretyczne i praktyczne aspekty badań ekologicznych. Idee Ekologiczne* (pp. 215–221). Wydawnictwo Sorus, Poznań 10(6).

Padisák, J., Borics, G., Grigorszky, I. & Soróczki-Pintér, E. (2006). Use of phytoplankton assemblages for monitoring ecological status of lakes within the Water Framework Directive: the assemblage index. *Hydrobiologia* 553: 1–14. DOI: 10.1007/s10750-005-1393-9.

Peckham, S.D., Chipman, J.W., Lillesand, T.M. & Dodson, S.I. (2006). Alternate stable states and the shape of the lake trophic distribution. *Hydrobiologia* 571: 401–407. DOI: 10.1007/s10750-006-0221-1.

Pham, L., Brabyn, L. & Ashraf, S. (2016). Combining QuickBird, LiDAR, and GIS topography indices to identify a single native tree species in a complex landscape using an object-based classification approach. *International Journal of Applied Earth Observation and Geoinformation* 50: 187–197. DOI: 10.1016/j.jag.2016.03.015.

Picińska-Fałtynowicz, J. & Błachuta, J. (2012). *Klucz do identyfikacji organizmów fitoplanktonowych z rzek i jezior dla celów badań monitoringowych części wód powierzchniowych w Polsce.* Bibl. Monit. Środ., Inspekcja Ochrony Środowiska, Warszawa.

Scheffer, M., Hosper, S.H., Meijer, M.L., Moss, B. & Jeppeen, E. (1993). Alternative equilibria in shallow lakes. *Trends Ecol. Evol.* 8: 275–279. DOI: 10.1016/0169-5347(93)90254-M.

Skwierawski, A. (2010). Funkcjonowanie małych zbiorników wodnych w różnych typach krajobrazu. In J. Koc (Ed.), *Ochrona zasobów i jakości wody w krajobrazie wiejskim.* (pp. 175–195). Uniwersytet Warmińsko – Mazurski w Olsztynie, Wydział Kształtowania Środowiska i Rolnictwa, Polskie Towarzystwo Inżynierii Ekologicznej, Monografia nr 1, Olsztyn.

Solarska, J. & Solarski, H. (1993). Przemieszczanie składników biogennych w zlewniach rolniczo-leśnych na tle stosunków hydrologicznych na Pojezierzu Mazurskim. *Bibl. Monit. Środowiska*: 218–231.

Szoszkiewicz, K., Jusik, S. & Zgoła, T. (2010). *Klucz do oznaczania makrofitów dla potrzeb oceny stanu ekologicznego wód powierzchniowych w Polsce.* Bibl. Monit. Środowiska. Główny Inspektorat Ochrony Środowiska, Warszawa.

Szpakowska, B. (1999). *Występowanie i rola substancji organicznych rozpuszczonych w wodach powierzchniowych i gruntowych krajobrazu rolniczego.* Wydawnictwo Uniwersytetu Mikołaja Kopernika, Rozprawy, Toruń.

The Water Framework Directive. (2000).

Wilk-Wozniak, E.(2016). Fitoplankton. In T. Sądag, T. Banduła, T. Materek, G. Mazurkiewicz-Boroń & R. Słonka (Eds.), *Zbiornik wodny Dobczyce – Monografia* (pp. 158–166). Kraków, RZGW, MPWiK.

Wysocka-Czubaszek, A. & Banaszuk, P. (2003). Migracja składników azotowych i bariery biochemiczne w zalewowych dolinach rzecznych na przykładzie Doliny Górnej Narwi. *Acta Agroph.* 2(1): 349–354.

Zębek, E. & Szymańska, U. (2017). Abundance, biomass and community structure of pond phytoplankton related to the catchment characteristics. *Knowledge & Management of Aquatic Ecosystems* 418: 45. DOI: 10.1051/kmae/2017036.