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Surface water quality monitoring in a large dam reservoir, Poland

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ABSTRACT

The paper presents a research monitoring platform implemented for the Sulejow dam reservoir located in Central Poland; the goal was to assess the quality status of the reservoir's waters during the vegetation season of 2015. Article presents the results of mobile field measurements together with laboratory analyses of biogenic parameters, in order to provide a broad picture of changes in water quality during the analysed period. Changes in water quality were evaluated based on the following parameters: chlorophyll a, ammonium ions, pH, water temperature, blue-green algae concentration, conductivity and dissolved oxygen. Analysis was complemented by laboratory measurements of the chemical parameters: nitrates, phosphates, 5-d biochemical oxygen demand, chemical oxygen demand and total organic carbon. Extensive mobile experiments enabled the mapping of the distribution of contaminants in the lake (ArcGIS). Chlorophyll a exceeded allowable values during the entire vegetation season; furthermore, the high water temperatures, high concentrations of dissolved oxygen and low concentrations of biogenic compounds illustrate the advanced eutrophication of the reservoir. Present conditions prevent any recreational use of the reservoir and generates not only environmental but also economic losses.

Keywords: Eutrophication; MONSUL; Sulejow dam reservoir; Water quality

1. Introduction

Surface water resources such as rivers, lakes and dam reservoirs are exposed to strong human pressure. They should, therefore, be subject to special protection, and any action must be thought through, properly evaluated and systematically controlled.

Overall, more than half of the river and lake water bodies in Europe are reported to have an ecological status or potential which is rated lower than good.

The pressures reported to affect most surface water bodies are pollution from diffuse sources, in particular from agriculture, causing nutrient enrichment. Hydromorphological pressures also affect many surface water bodies, mainly from hydropower, navigation, agriculture, flood protection and urban development, resulting in altered habitats. A large proportion of water bodies have poor ecological status and are affected by pollution pressures, particularly in Central and Northwestern European areas with intensive agricultural practices and high population density.

A dam reservoir represents a relatively complex hydrodynamic system in comparison with a lake, and is characterized by a dynamic inflow of water containing a large amount of debris and contaminants. A continuous supply

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of nutrients with river water causes a significant increase in the trophic status of the reservoir waters. The quantitative and qualitative aspects of the supply of nutrients and other chemical compounds depend on the method of management of the catchment, the loading of the reservoir with point- and surface run-offs, and the amount and composition of the rainfall and groundwater supplying the water body [1].

Water quality in lakes and dams is undergoing continuous degradation caused by natural processes and due to the anthropogenic reasons. On the other hand, the diversity of needs and priorities by which surface waters are assessed is remarkable. Activity zones that are taken into account include household water supply, agriculture, transport, hydropower, fisheries, recreation and flood wave control. Therefore, the amount of water in rivers, lakes and reservoirs should be assessed strictly depending on the priority needs of a specific case being considered. Treating water conservation as a whole, it should be emphasized that only about 50% of biogenic pollution load originates from point sources (N, P). The remaining 50% comes from dispersed sources. Therefore, even an excellent sewerage may fail to prevent degradation of sensitive receivers. The scale of the problem is reflected by water blooming. This problem affects primarily the eutrophised (rich in nutrients) lakes and reservoirs. Multifaceted usage of reservoirs is possible only if ecological values of the geosystems, especially good quality of water, are retained. This quality is derived from environmental conditions and the way in which maintenance drainage areas are developed. Identification of relationships and interactions in the drainage basin–reservoir system helps indicate optimal forms of land use, triggering protection of water resources.

Optimum use and correct management of water resources in Poland are crucial as:

- Poland is distinguished by relatively low levels of water resources (ca. 1,500 m^3/year/capita), a high population and diverse conditions of urbanisation and management of the area. National water resources constitute only about 36% of the European average;
- Local water shortages are common;
- There is an underdevelopment of technical infrastructure and surface water bodies are of poor quality.

These factors mean that reasonable water management is difficult. The relatively small retention volume of the artificial reservoirs in Poland does not compensate for problems arising from periodic surpluses and deficits of surface waters. The primary problem in terms of supplying the population with water is the low availability of high-quality water; due to a marked decrease in consumption from industry and households, problems with quantity have become much less significant.

Water quality in Poland depends strongly on the method of managing drainage basins. For example, sewage from neighbouring holiday resorts, tourist cabins, camping sites and other nearby buildings where sewage management has not been properly arranged may reach lakes and reservoirs used for recreational purposes. The recreational use of lakes is often accompanied by a process of deterioration of the shores and waterside vegetation, which contributes to soil erosion and impoverishment of the vegetation and, as a consequence, enhances the inflow of substances from the drainage basin to the lake [2]. The care and protection from degradation of water resources should be a main objective of public administration authorities, research centres and all inhabitants of the region.

1.1. Study area

The Sulejow dam reservoir, located 40 km south-east of Lodz (Poland), was built in the early 1970s. No large water reservoirs existed in the area at the time, and the reservoir was intended to address the increase in demand for water and to support the rapidly expanding Lodz population (Fig. 1). The reservoir is a typical, shallow lowland reservoir, taking up a large area, was created as a result of damming the Pilica river. A concrete and soil dam with the length of 1,200 m and the height of 16 m was constructed on the 139th kilometre from the mouth and resulted in the creation of a reservoir with the surface area of 2700 ha.

The reservoir water supply comes mainly from two rivers: Pilica and Luciaza.

Basic description of the Sulejow dam reservoir:

- length 17.1 km,
- maximum width 2.1 km,
- average width 1.5 km,
- average depth 3.3 m,
- maximum depth 11 m,
- shoreline length 58 km,
- usable volume 61 million m^3,
- maximum volume 75 million m^3,
- catchment area 4,900 km^2.

The functions of the reservoir are still evolving; initially a site for storing water, it has now become an important location for recreation, water sports and a unique and very complex ecosystem with variety of plant and animal species [3]. This evolution of the reservoir strongly impacted the local economy, farming, water retention and microclimatic conditions. The water condition is currently degrading, due to the unconstrained volumes of pollutants draining into the reservoir, resulting in the excessive growth of blue-green algae (BGA) during summer. This process is harmful and dangerous to every activity and use of the natural qualities of the reservoir. Furthermore, the low potential of the waters and the susceptibility to eutrophication directly affect the condition of the local ecosystem. These hazards should, therefore, be controlled, predicted and reduced as far as possible. A complete meteorological, hydrological and chemical database can form a basis for making decisions and implementing remedial actions.

1.2. Monitoring the water of the Sulejow dam reservoir

At the beginning of 2015, a research program was launched at the Faculty of Process and Environmental Engineering at Lodz University of Technology to monitor the environment of the Sulejow dam reservoir catchment area, to determine the effect of factors negatively affecting water quality and to identify the dynamics of changes in the indicators describing the ecological potential (MONSUL, http://www.monsul.wipos.p.lodz.pl). A system of direct and continuous monitoring measurements covering virtually the entire surface area of the Sulejow dam reservoir was implemented in collaboration with the Faculty of Geographical Sciences of the University of Lodz and the Norwegian Institute for Water Research of Oslo as part of the project.

In accordance with the requirements of Directive 2000/60/EC of the European Parliament and the Council of 23rd October 2000 establishing a framework for community action in the field of water policy (Water Framework Directive), the types of surface waters in Poland were defined, followed by a determination of the bodies of water which form the basic unit of water management [4].

The evaluation of the condition of surface waters (rivers, lakes, transitional waters and coastal waters) is performed in relation to bodies of water, based on the results of national environmental monitoring and presented by the evaluation of the ecological condition/potential and chemical condition.

In accordance with the regulations from the Minister of Environment of 21st November 2013 (Dz.U. 2013 item 1558), three types of monitoring are determined: diagnostic, operational and research, with monitoring of protected areas

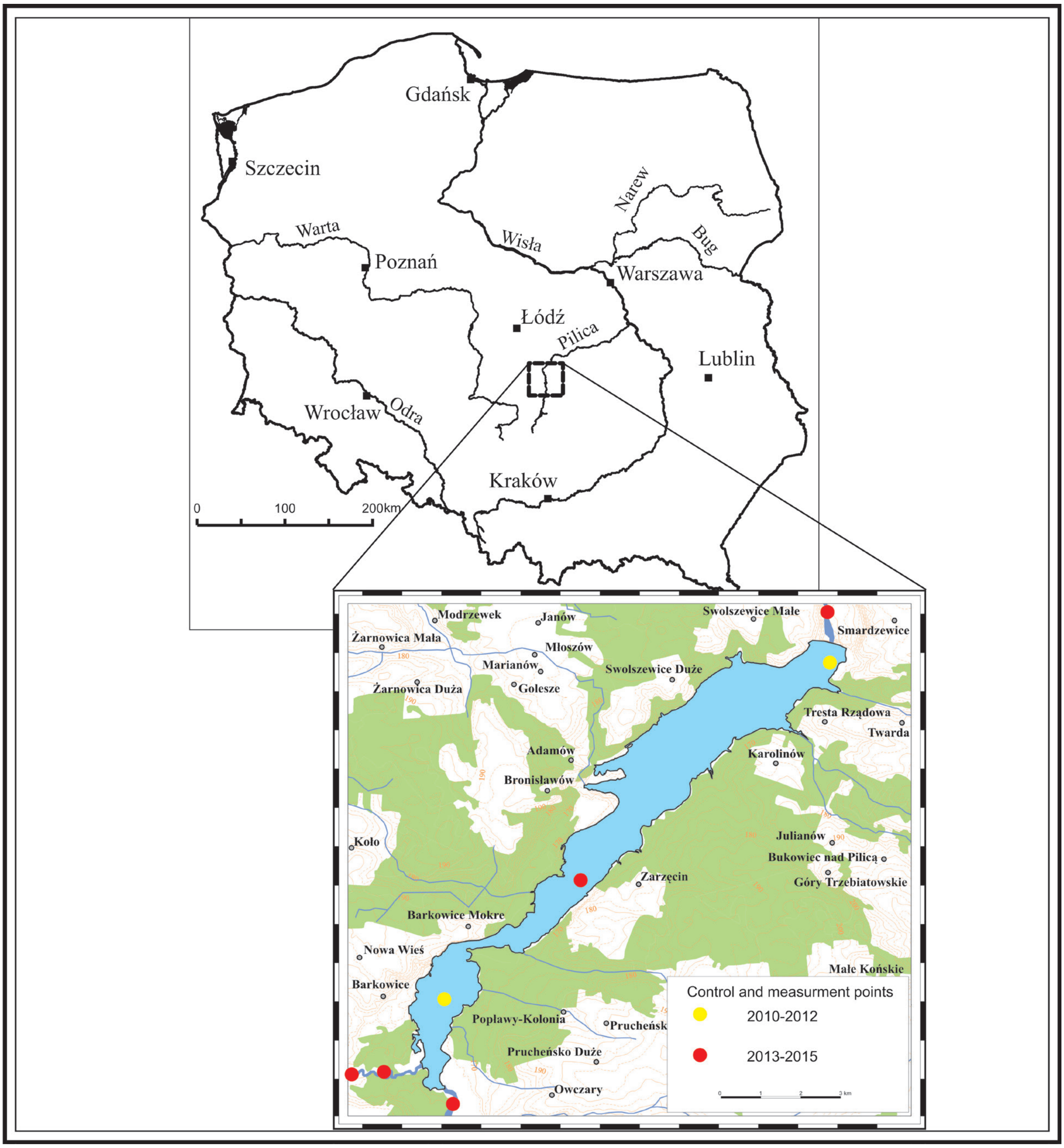

Fig.1 Location of the Sulejow Dam Reservoir with marked control and measurement points in years 2010–2015 [7].

additionally identified. According to these guidelines, the Sulejow dam reservoir is tested as follows:

- Every 6 years for diagnostic monitoring, taking into account almost 100 indicators, including biological elements, basic physical chemistry (physical state, oxygen condition, salination, acidification, biogenic substances), particularly harmful substances (specific synthetic and non-synthetic pollutants) and chemical condition (priority substances). The purpose of diagnostic monitoring is the identification of pollutants occurring in excessive amounts, the determination of the condition of the body of water, the tracking of long-term changes caused by anthropogenic effects and the provision of information for planning future monitoring programmes;
- Every 3 years for operational monitoring, taking into account biological elements and basic physical chemistry. The purpose of this is to determine the condition of the body of water and to track the effects of actions implemented in order to improve water condition. Furthermore, every 3 years, additional requirements must be met for recreational areas, including swimming areas and protected areas susceptible to eutrophication due to municipal pollution sources;
- Every year for operational monitoring of priority substances for which the concentrations exceeded those in previous years. In the new research cycle, priority substances with significant and excessive amounts will be specified every year.

Monitoring activities on the Sulejow dam reservoir run by the Voivodship Inspectorate for Environmental Protection are adequate for legal requirements and are limited to basic operational monitoring every 3 years, and annual testing of problematic indicators and detailed (diagnostic) examinations on a broad analytical spectrum every 6 years. Since 2013, the aforementioned parameters have been analysed at only a single control and measurement point on the reservoir, near the town of Zarzecin. The remaining control and measurement points cover the rivers supplying the reservoir (Pilica–Sulejow, Pilica–Smardzewice, Luciaza–Przygłow and its left-bank tributary Luciaza–Strawa) (Fig. 1). This indicates that the current monitoring programme for the reservoir does not provide a full picture of the changes in the reservoir and does not contribute to an adequate evaluation of the dynamics of processes affecting its potential. For this reason, it is crucial to develop observational monitoring systems within the artificial lakes which are capable of collecting both high-resolution and long-term data, and to construct multi-disciplinary data sets. Recent advances in communication and sensor technology have led to the development of multi-platform networks that provide a significant amount of data at different spatial and temporal scales for the study of processes taking place in man-made ecosystems [5].

The need for the constant and ongoing monitoring of changes in water quality, for example, in the dam reservoir on the upper Vistula River in Goczalkowice, is confirmed by results reported by Absalon et al. [6].

2. Experimental methods and procedures

The monitoring programme launched within the framework of the MONSUL project consists of the following compatible research platforms:

- A mobile, floating measuring system equipped with an EXO2 probe and GPS and
- An off-line measuring system where water samples taken from the reservoir were analysed in the laboratory.

The mobile measuring system consists of an EXO2 probe and a GPS module, which was used for determining global position at the moment of measurement. The measurement set used for testing involved the EXO2 probe (YSI, USA) and the DT80 (TECHNIKA IT SA, Gliwice, Poland) measurement data collection and transmission system.

The system was mounted on a motorized boat, allowing the researchers to cover the entire reservoir over a period of approximately 10 h. During this period, the probe was towed next to the side of the boat and the following parameters were measured: water temperature, pH, dissolved oxygen concentration, conductivity, chlorophyll and BGA concentration and the content of ammonia ions. In this case, the probe was submerged to a depth of 1.5–2 m below the surface of the water. The motorized boat moves at a speed of approximately 6 km/h. This speed was adjusted to minimize errors arising from the inertia of the measurement sensors while at the same time allowing the completion of a full cycle of tests along the route of approximately 40 km within a single day of measurement. Measurement data were recorded using a data logger and downloaded onto the computer after the trip was completed. The use of the probe with the data recording system enabled the measurement and recording of values, including the time and location of measurement, at a frequency of every 2 min. A single trip provided information on the water quality on the day of measurement at 650–700 points located across the entire reservoir. During the summer season of 2015, 12 trips were completed, providing results from several thousand measurement points for further analysis. At each measurement point, the probe measured six water quality parameters. The intention of the programme of mobile measurements was to obtain data along the entire length of the reservoir from the dam to the town of Barkowice from the main flow of the water course as well as from bays, marinas and river mouths. An example of an actual route for the motorboat measurements, tracked with a GPS system, is shown in Fig. 2.

The measured values were then processed and transformed into 2D point distribution maps for each of the measured parameters along the route of the boat, with the aid of the GIS system (ArcGIS, ESRI, USA). An example cruise depicting the distribution of the chlorophyll a concentrations in the Sulejow Reservoir on 14th July 2015 is presented in Fig. 3.

2.1. Off-line measurements

During each monitoring trip on the reservoir, approximately 30 water samples were collected from selected points on the lake. Water samples were analysed in the laboratory using an off-line measurement system. In water samples

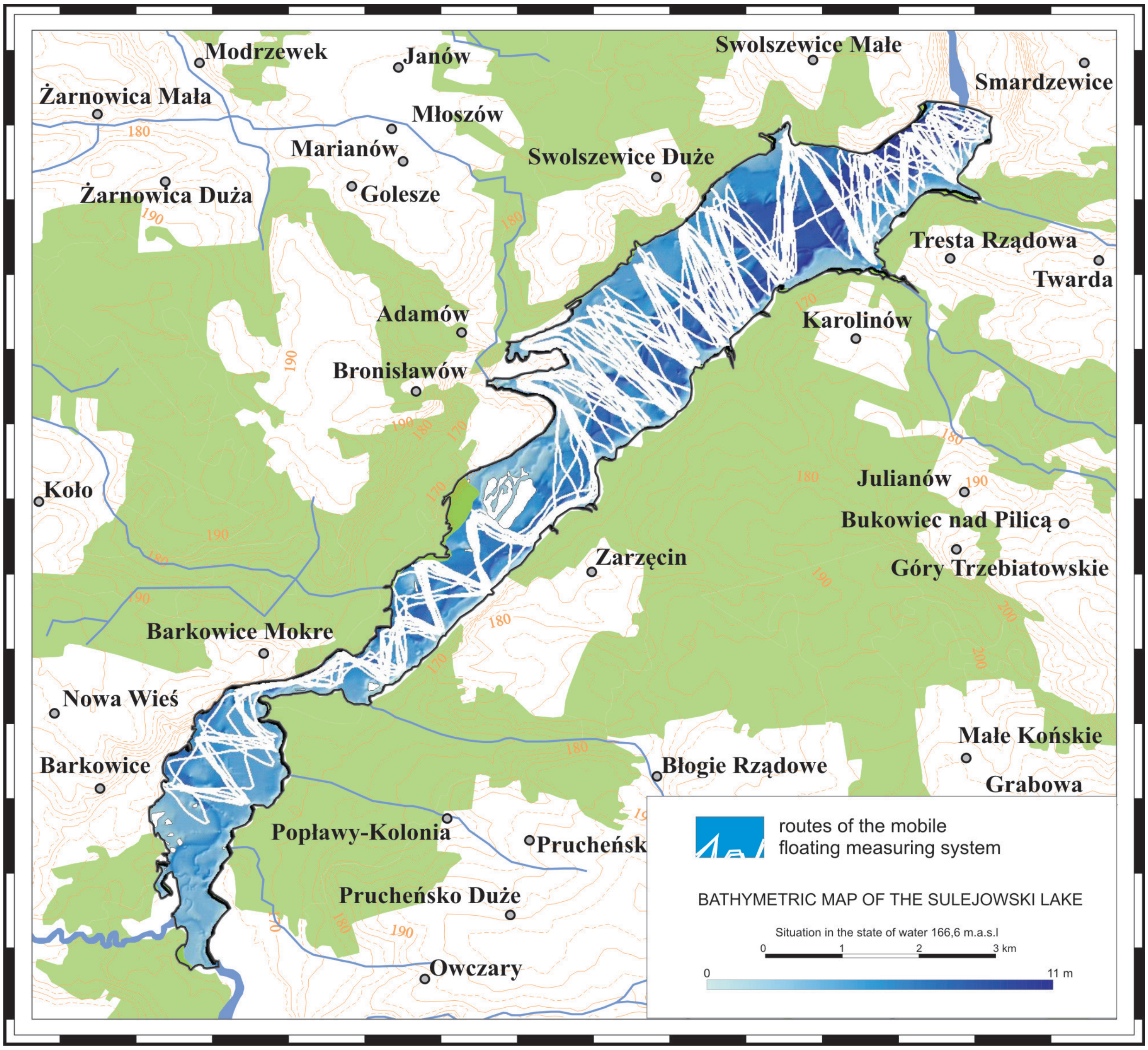

Fig. 2. Example of motorboat trips with the measurement probe, created by transferring the GPS boat locations onto the bathymetric map of the Sulejow Reservoir.

taken from the reservoir, the following parameters were analysed: chemical oxygen demand (COD), 5-d biochemical oxygen demand (BOD_5), total organic carbon (TOC), nitrate nitrogen (NO_3^--N) and phosphates (PO_4^{3-}). A grab sampling procedure was used, in which samples were taken manually a few centimetres below the water surface. The methodology used for determining water quality parameters was consistent with the standards applied to the monitoring of surface water quality. The water quality indicators listed above were measured with a spectrophotometer using tests provided by HACH LANGE GmbH. COD was determined using dichromate methods in the presence of silver sulphate as a catalyst. This analysis was in accordance with the ISO 6060-1989 standard.

Determination of BOD_5 involved the determination of dissolved oxygen within sample concentrations, both on the day of sampling and after 5 d incubation of the samples at a constant temperature of 20°C. The oxygen concentration in the samples was measured in an alkaline solution in the presence of a derivative of pyrocatechol and Fe^{2+} ions. This analysis was carried out in accordance with the EN 1899-1 standard. TOC was determined by mineralization of organic compounds in a microwave oven at 100°C for 2 h. Under these conditions, organic compounds were completely oxidized to CO_2, the amounts of which were measured by spectrophotometric methods. This analysis was in accordance with the DIN 38409-H3 standard. Nitrogen levels in the form of NO_3^- were determined by a reduction of NO_3 to nitrate(III) and by the reaction of these ions with sulphanilic acid and chromotropic acid. The coloured products of these reactions were measured using spectrophotometric methods. Phosphate (PO_4^{3-}) concentrations were determined by the reaction of these ions with potassium molybdate in the acid solutions. The concentration of the coloured ions obtained was determined using spectrophotometry. The determination of PO_4^{3-} was in accordance with the PN-EN ISO 6878-2006 standard. All of

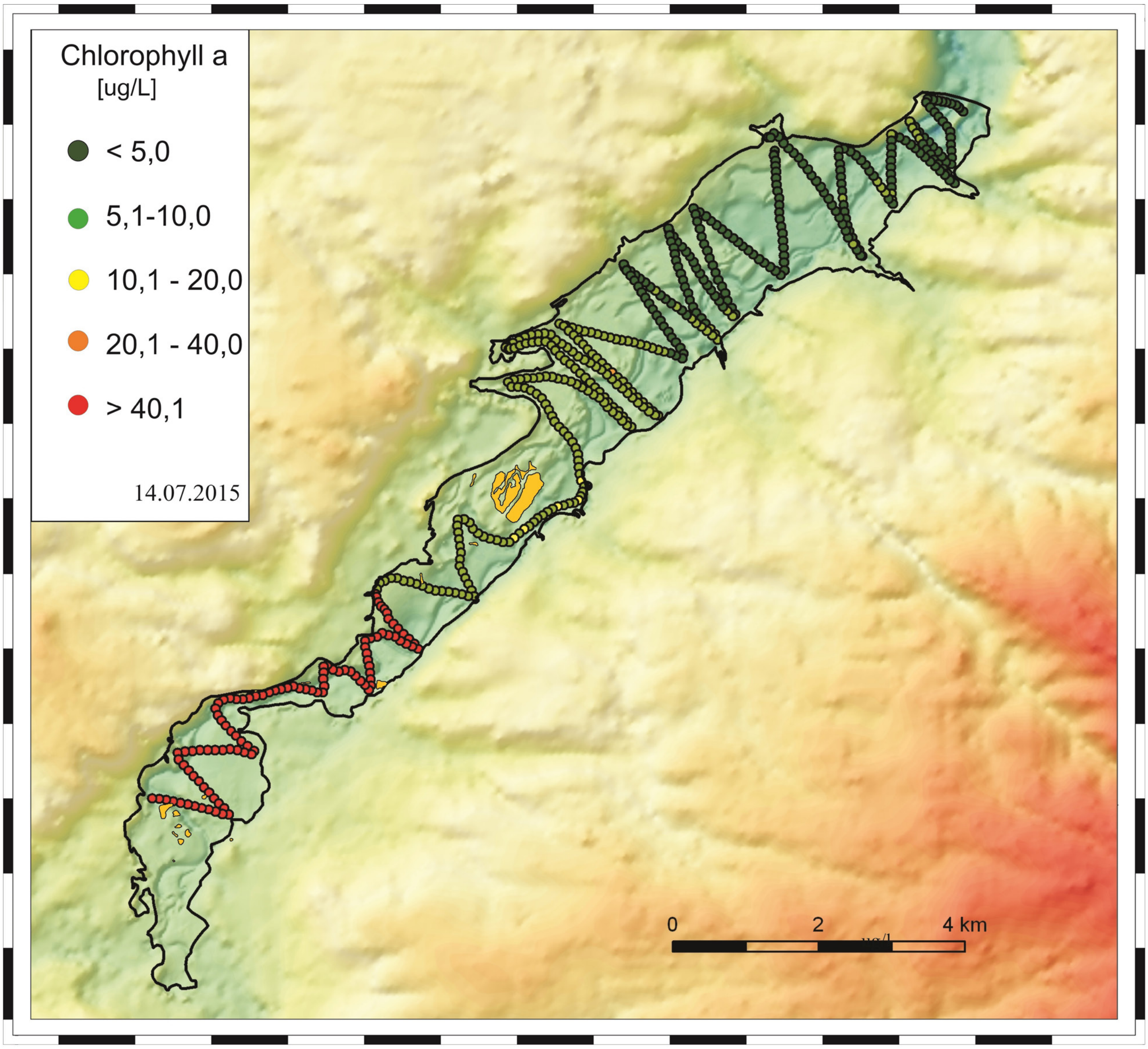

Fig. 3. Distribution of chlorophyll a concentrations (μg/L) in the Sulejow Reservoir along the route of the motorboat and probe on 14th July 2015.

the above mentioned analyses were performed twice, and the final value was the average of two comparable measurements.

3. Results

Laboratory measurements of water samples were carried out every month, beginning in May 2015, and were continued until the end of September 2015. As pointed out earlier, 2015 was an unusually dry year. The climatic water balance in the region of the Sulejow reservoir was negative at that time, with changes in rainfall deficit within the following ranges: –143.4 mm in May to –200.2 mm in September 2015 (in 2014, the climatic water balance of the Sulejow community was –14.3 mm in May and –8.4 mm in September) [8]. For this reason, the water levels in the Sulejow reservoir and in the Pilica and Luciaza rivers were low, and this affected the distribution of contaminants in the lake.

Plant development in surface waters is affected by a number of factors, including light, temperature and the morphological, hydrodynamic and hydro-biological properties of watercourses and reservoirs. Elements necessary for the development of aquatic vegetation are biogenic compounds such as hydrogen, carbon, nitrogen, oxygen, phosphorus, sulphur, sodium, magnesium, potassium, calcium, iron, manganese, zinc and tin. However, the primary factors controlling the process of eutrophication are nitrogen and phosphorus compounds [9].

Phosphorus is an essential nutrient for life. Humans have massively altered the global phosphorus cycle by increasing the loading on river systems through fertilizer use, soil erosion and wastewater discharges [10]. Since P limits or co-limits the primary productivity of many aquatic ecosystems, increased river fluxes of P have been identified as a main cause of eutrophication of surface water bodies.

The changes in orthophosphate(V) concentrations at the critical points on the Sulejow reservoir between May and September 2015 are presented in Table 1 and Fig. 4.

The data presented in Table 1 and Fig. 4 show that high phosphate levels were observed in the waters of the Luciaza River in the period May to September 2015. These concentrations of orthophosphate(V) were within the range 0.28–0.335 mg PO_4^{3-}/L and occasionally exceeded the limits established for Class II water quality [11] ($W_{G(II)}$ < 0.31 mg PO_4^{3-}/L). Concentrations of phosphate(V) in the Pilica River were not as high as in the Luciaza River, although during the month of August, concentrations of PO_4^{3-} were observed which exceeded the limits for Class II water quality. In the Sulejow reservoir water body, phosphate levels in May and June were not higher than average levels of these compounds in the tributaries supplying the reservoir.

Table 1
Changes in orthophosphate (V) concentrations (mg PO_4^{3-}/L) in the Sulejow dam reservoir between May and September 2015.

No.	Measuring points	28.05.2015	25.06.2015	22.07.2015	26.08.2015	21.09.2015
1	Przyglow (Luciaza)	0.280	0.315	0.335	0.285	0.29
2	Pilica Inflow	0.110	0.150	0.130	0.325	0.235
3	Barkowice Mokre	0.183	0.105	0.045	0.160	0.175
4	Zarzecin	0.090	0.233	0.055	0.215	0.115
5	Bronislawow	0.100	0.160	0.035	0.170	0.315
6	Karolinow	0.100	0.145	0.065	0.110	0.235
7	Smardzewice	0.070	0.120	0.080	0.180	0.23
8	Pilica Outflow	0.065	0.175	0.205	0.255	0.17

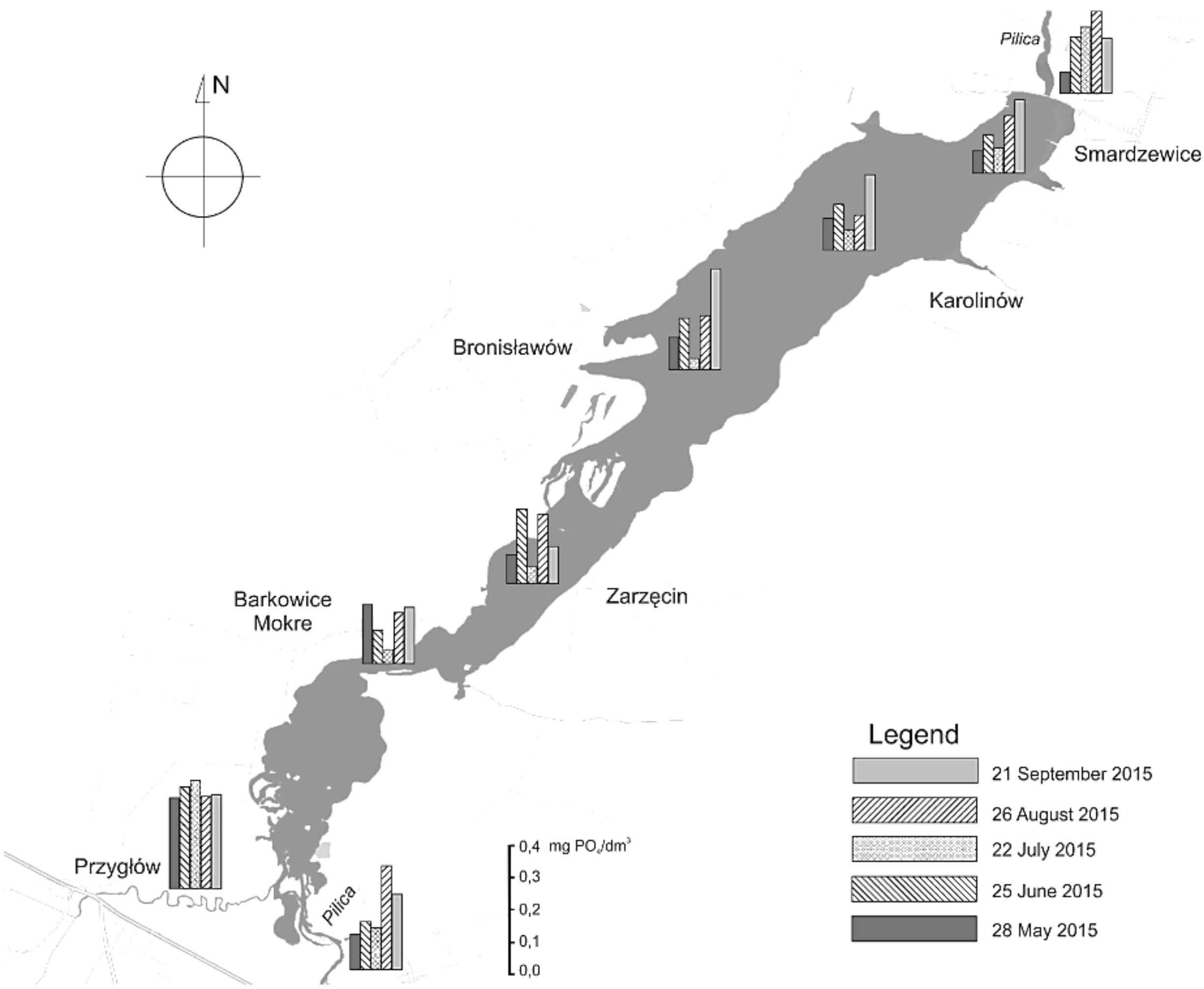

Fig. 4. Changes in PO_4^{3-} (mg/L) concentration at selected points of the Sulejow dam reservoir during the period May-September 2015.

These indicate that the Sulejow reservoir was not probably fed during the analysed period by phosphates derived from surface runoff or other direct sources of emissions. However, in July – during the intensive vegetation of phytoplankton – the concentrations of phosphate in the reservoir are lower than those observed in the waters of the Luciaza and Pilica rivers. During vegetation period, the phytoplankton assimilates large amounts of phosphates and the concentration of this substance in the reservoir decreases. The opposite process was observed in the post-vegetation period (end of August and September 2015). In this case, the concentration of phosphates in the Sulejow reservoir was higher than in the rivers flowing into the reservoir meaning that phosphates must have been released from decomposed phytoplankton and sediments.

Changes in nitrate(V) concentrations at selected points on the Sulejow dam reservoir during the period May–September 2015 are presented in Table 2 and Fig. 5. As can be seen from the data presented in Table 2, the concentrations of N-NO_3^- in the samples taken from the reservoir are much lower than those from the Luciaza and Pilica rivers. This confirms the assumption that surface runoff from agricultural fields surrounding the reservoir was very low between May and September 2015, and that the main load of nutrients was emitted from the tributaries to the Luciaza and Pilica rivers.

During the vegetation season, that is, in the period July–August, concentrations of nitrate ions in the Sulejow dam reservoir fell to almost zero. The above shows that NO_3^- ions are assimilated by the microorganisms present in the water. Nitrate ions are involved in the circulation of nitrogen compounds in the ecosystem and contribute to the growth of phytoplankton and intensive cyanobacterial blooms.

The intensive development of phytoplankton and the accompanying processes of photosynthesis during high temperatures and solar radiation result in an excessive state of oxygen saturation in the surface layers of water.

The content of dissolved oxygen is thus one of the most important indicators of water quality. Higher temperatures reduce the solubility of oxygen and increase the rate of oxygen-consuming biochemical processes; intensified photosynthesis processes, the major source of oxygen in water, lead to the supersaturation of the water with the gas. Such situations are common in eutrophic water bodies during the summer months; however, oxygen saturation seems to be solely a favourable phenomenon. In fact, it is evidence of the intense growth of phytoplankton, which in turn indicates a significant concentration of nutrients in the aquatic environment. During the periods of increased activity of biological life associated with this phenomenon, the processes of photosynthesis result in an increased concentration of oxygen index, characterized by the BOD. In the central section of the reservoir, the concentrations of BOD_5 exceeded 7 mgO_2/L.

Lack of stratification makes the deposit of chemical substances of allochthonic origin more difficult, and nutrients, therefore, rapidly circulate in the bio-system and intensify the primary production. The chlorophyll a content reflects the quantity of phytoplankton cells in water and is a measure of the intensity of primary production in the reservoir.

The characteristic feature of cyanobacterial bloom is their uneven, focal character, as evidenced by their distribution of concentrations shown in Fig. 5 in the year 2015. High concentrations of BGA appeared in the north-east part of the Sulejow reservoir, north of the largest, centrally located island. The blooms of cyanobacteria did not enter one of the strictly defined areas of the lake – their clusters appeared and disappeared in a relatively chaotic manner throughout the northeastern region of the reservoir. The formation of such areas where the cyanobacterial blooms are grouped is due to the hydrodynamics of water flow in the Sulejow reservoir, because the locations of the elevated BGA concentrations strongly correlate with the line patterns determined by the calculation and simulation of water flows in the reservoir.

The concentration of chlorophyll a in the Sulejow reservoir at the beginning of the vegetation season was higher in the lacustrine part of the reservoir. In July, the riverine, shallower part of the lake was more susceptible to algal bloom, and the concentration of chlorophyll a exceeded standards for first-class purity (10 μg/L). The strong correlation between temperature and both chlorophyll a and BGA concentration is notable. The presence of ammoniacal nitrogen (ammonium ion) in the surface waters may be the result of natural plant matter decomposition or indicative of pollution with municipal sewage. In the case of the Sulejow reservoir, the highest concentrations of this parameter are observed near the marinas and locations of concentrated human residence (exceeding 0.5 mg/L). As the pH increases to above 7 (in the tested season, pH values were between 7.5 and 8.5), poisonous ammonia (NH_3) is found together with ammonium ions, due to chemical reactions. The concentration of ammonia increases with an increase in pH. Spatial distribution of ammonium ion concentrations in the

Table 2
Changes in nitrate concentrations (mg N-NO_3^-/L) in the Sulejow dam reservoir between May and September 2015.

No.	Measuring points	28.05.2015	25.06.2015	22.07.2015	26.08.2015	21.09.2015
1	Przyglow (Luciaza)	0.980	0.515	0.440	0.425	0.545
2	Pilica Inflow	0.260	0.577	0.155	0.475	0.35
3	Barkowice Mokre	0.300	0.185	0.001	0.275	0.075
4	Zarzecin	0.210	0.185	0.010	0.060	0.07
5	Bronislawow	0.190	0.150	0.010	0.010	0.05
6	Karolinow	0.175	0.085	0.001	0.001	0.01
7	Smardzewice	0.175	0.060	0.010	0.010	0.015
8	Pilica Outflow	0.155	0.055	0.01	0.01	0.015

Sulejow reservoir is uniform. Only in the vicinity of Barkowice village, in the summer and – in particular – in the fall period, elevated NH_4^+ concentrations of 1.0 mg/L are observed. Elevated concentrations of this ion may indicate an increased anthropopressure occurring in this area in September (Figs. 6(a)–(c)).

The results show that the water in the reservoir corresponds to Class II [11] purity in terms of TOC content, and exceeds value allowed for this standard of purity, that is, 15 mg TOC/L. TOC is a direct measurement of the contents of organic compounds in surface waters, and BOD_5 and COD serve as auxiliary parameters. COD at the beginning of the vegetation season reached the maximum value for Class II purity, that is, 30 mg/L, whereas in July and August, in the entire reservoir and the supplying rivers, it reached a value typical of Class I purity. At the end of August and during September, the concentration of organic matter increased, particularly in the upper, narrower part of the reservoir.

4. Conclusions

Water in artificial reservoirs used for planned human activity of various types, such as drinking water storage or for tourism, recreation and sports, should be of high quality. It is, therefore, necessary to carry out frequent monitoring of the water, record the results, analyse the causes of changes and monitor risks.

Monitoring data obtained within the framework of the National Programme of Environmental Monitoring in the years 2010–2015 does not provide sufficiently complete information about the changes in and dynamics of the processes taking place in the Sulejow reservoir's water body. An extensive research monitoring programme launched in January 2015 as part of the MONSUL project allowed a more comprehensive assessment of the ecological status of the reservoir's water. The data obtained from direct, continuous measurement of all the water bodies of the Sulejow reservoir are crucial for understanding the mechanisms and dynamics of algae blooms taking place in the water.

Continuous monitoring provides a more detailed view of the water quality during the vegetation period; it enables rapid detection when allowed values are exceeded and the implementing of the necessary practical steps to improve water quality.

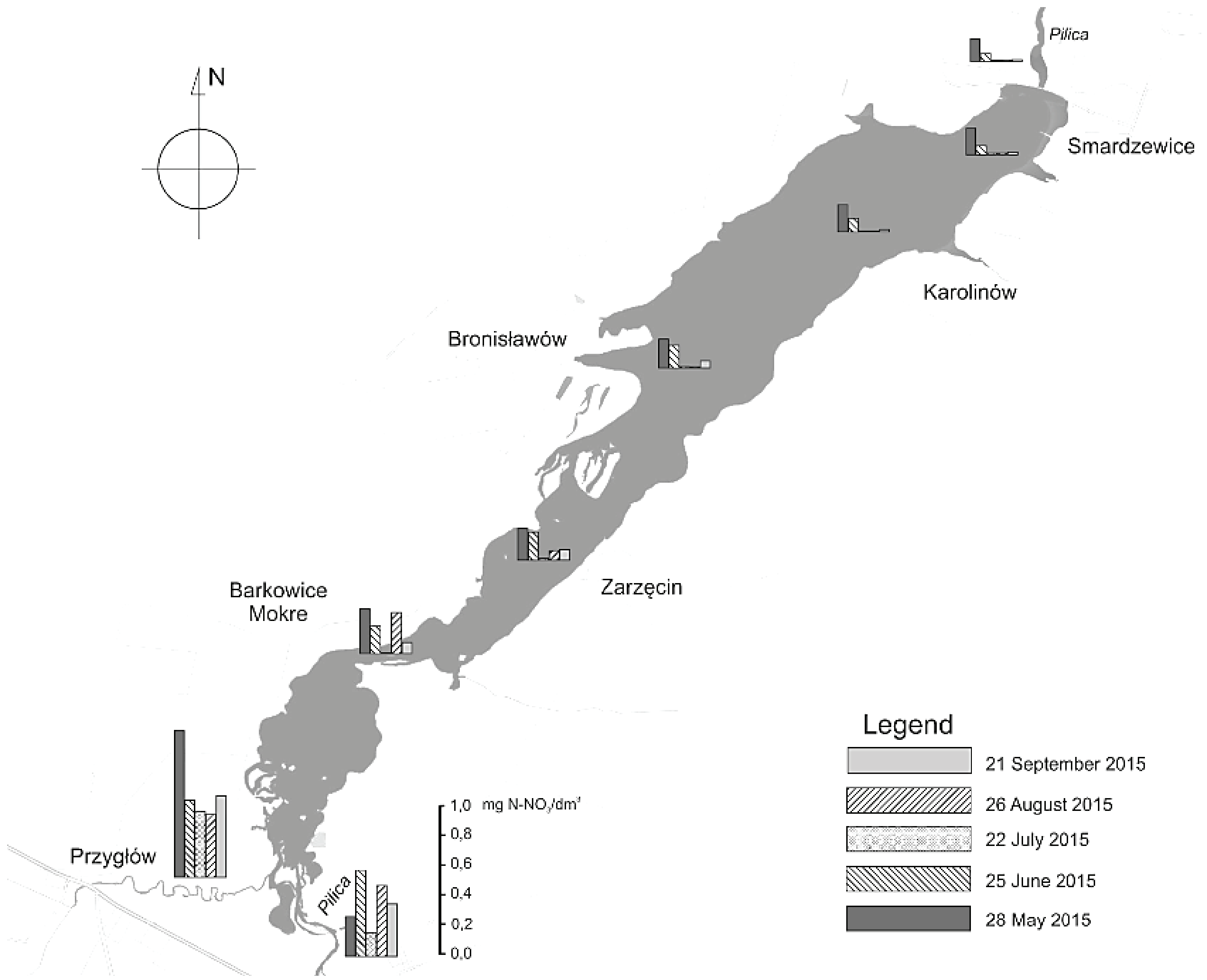

Fig. 5. Changes in N-NO_3^- (mg/L) concentration at selected points of the Sulejow dam reservoir during the period May-September 2015.

(a)

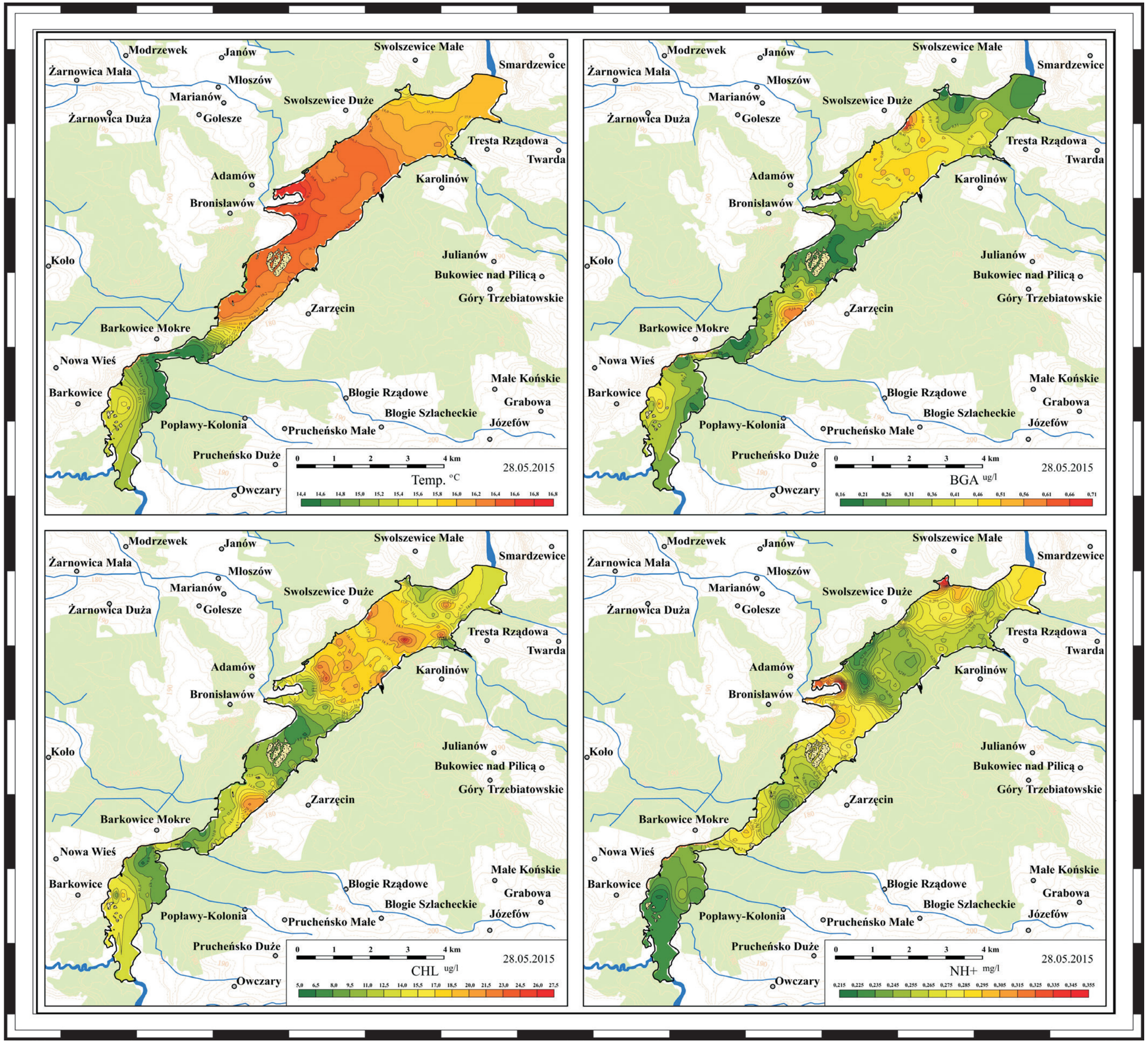

Fig. 6. Spatial distribution of the temperature (°C) and concentration of chlorophyll a (μg/L), BGA (mg/L) and NH_4^+ (mg/L) in the surface water of the Sulejow reservoir in May 2015 (a), June 2015 (b), July 2015 (c).

(b)

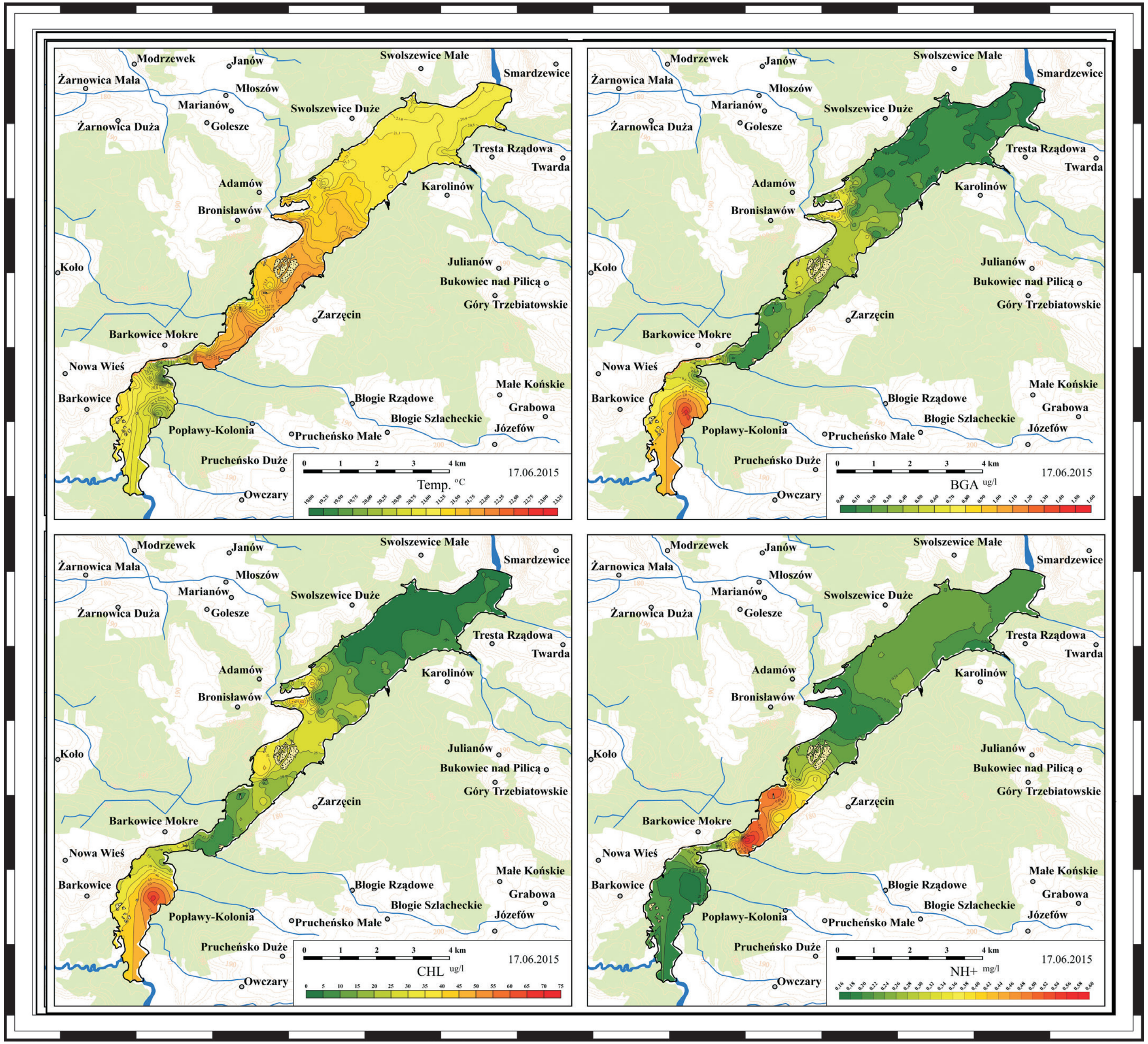

Fig. 6. (*Continued*)

(c)

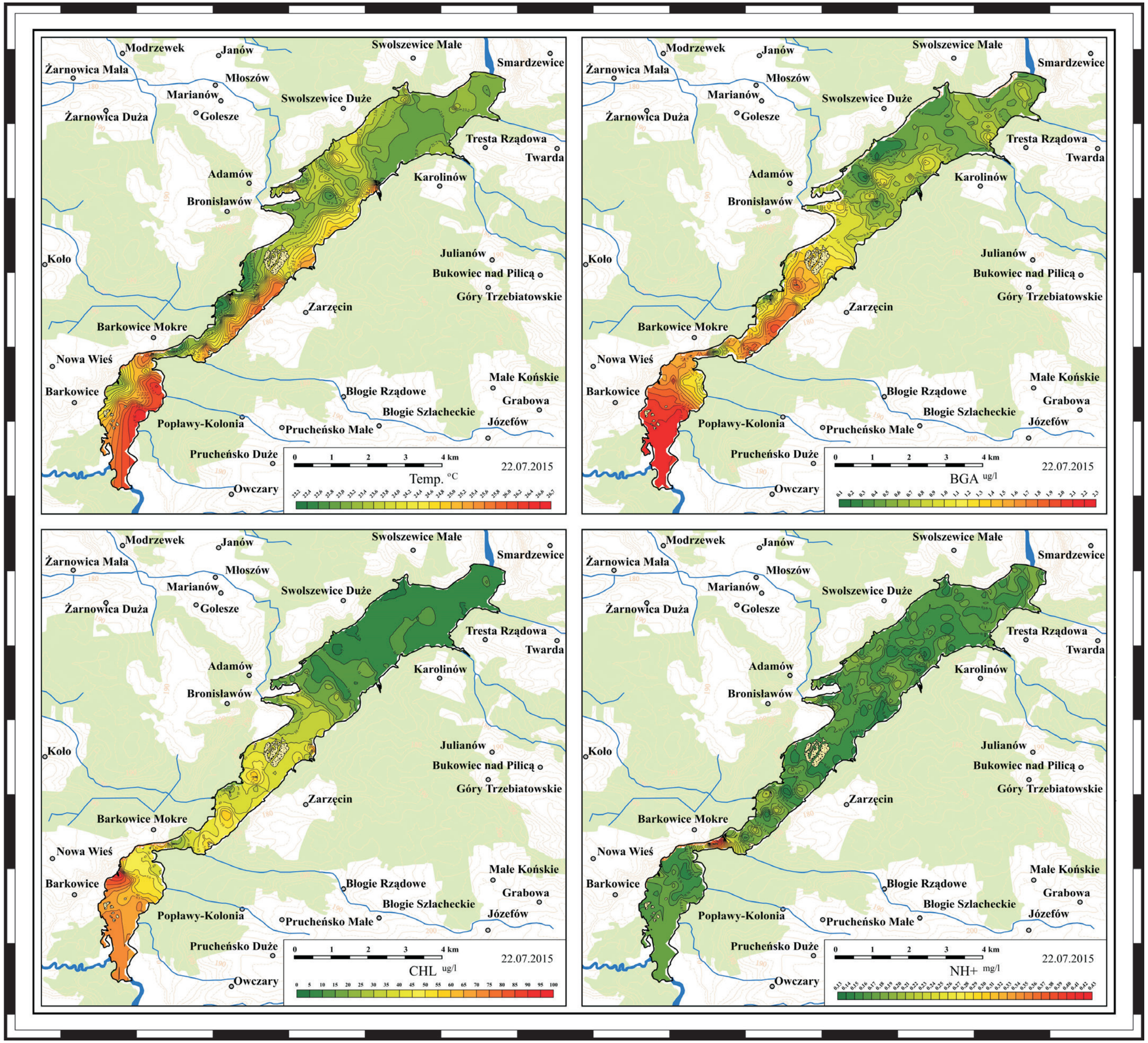

Fig. 6. (*Continued*)

For the first time, a multi-parameter probe was used to take mobile measurements, and the quality of these results was confirmed with reference to prior testing. Motorboat trips provided a series of local data which were interpolated using the ArcMap and Spatial Analyst software and visualized as maps. The resulting maps can be used to compare each of the measured water parameters in terms of spatial distribution and to track these changes over the time period analysed.

The biogenic compounds investigated demonstrated considerable variation within the reservoir, as well as over the season in question. High water temperatures increase the eutrophication process and provide ideal conditions for the growth of cyanobacteria, as confirmed by high chlorophyll a and algae concentrations during the entire vegetation season, across the entire reservoir and particularly in the northern part of the reservoir during July and August. The concentrations of nitrates and phosphates are higher in the rivers supplying the reservoir (Pilica and Luciaza) and this testifies to the decreased surface run-off of these substances due to the very dry summer of 2015 and the resulting decrease in water levels.

These research results obtained using a complementary monitoring program allow for a comprehensive assessment of the ecological status of Sulejow reservoir.

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