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GLEBOKIE LAKE IN SZCZECIN AFTER HYDROTECHNICAL REGULATIONS

JEZIORO GŁĘBOKIE W SZCZECINIE PO PRACACH HYDROTECHNICZNYCH

Abstract: Water quality of the Glebokie Lake in Szczecin (NW-Poland) was studied in years 2012-2014. Glebokie Lake is a reservoir with a negative water balance related to the location draining groundwater drinking water intake for Szczecin agglomeration. In 2004 hydrotechnical regulations were conducted aimed at maintaining a constant amount of water in the lake, which involved a temporary feeding Glebokie Lake with Gunica River waters. In order to determine the hydrochemical status of the Lake waters and the factors shaping water quality - 19 water quality indices within 25 months were measured: temperature, pH and water oxygen status, nutrients (N, P) and ionic macrocomponents and Fe_{tot}. Trophic status of the lake waters using the Carlson criteria was defined. On the basis of chemometric analysis of measurement data (CA, PCA/FA and DA) we established that statistically significant factors affecting water quality in the study period were: seasonal (the climatic seasons) changes in the biological processes activity, periodical (in April and November) waters inflows from the Gunica River, anthropopressure in during swimming season and the coagulant ($FeSO_4$) presence in the ecosystem. The possibility of applying the chemometric techniques to interpret measurement data in the lake type like Glebokie Lake with a small amount of data has been shown.

Keywords: urban lakes, hydrotechnical restoration, water quality, chemometric analysis

Introduction

The climatic changes and constantly increasing anthropopressure cause fast transformations in lake ecosystems, mainly regarding their abundance in water and this results in significant changes in water quality and biocoenosis alterations.

The effects are particularly fast occurring in lakes devoid of surface inlets and outlets which frequently turn into reservoirs with negative water balance manifested by lowering the water level in the tank. In a drastic way phenomenon occurs, *eg* in Asia [1-4]. However,

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it is also present in central Europe [5-11]. Glebokie Lake in Szczecin (NW-Poland) is a very example of such a lake. The negative water balance in this lake is caused by strong anthropopressure resulting primarily from an excessive exploitation of a water intake in close proximity (water intake station in Pilchowo). In order to stabilize water volume in the lake, a supply pipeline from the Gunica River was constructed since 2004, delivering annually as much as 30% of the lake volume [12, 13]. Having the water balance stabilized, the Glebokie Lake became a reservoir replenishing the aquifer in the Pilchowo water intake zone.

The presented study was an attempt to determine hydrochemical status and factors influencing water quality in the Glebokie Lake in the years 2012-2014 using chemometric analyses especially cluster analysis (CA), principal component analysis/factor analysis (PCA/FA) and discriminant analysis (DA) [14, 15], which is possible with the short measurement series [16, 17]. Chemometric procedures were often used for conducting studies on the quality of natural waters - including lake water [18-24]. Most of the works is a study of river waters in the catchment [25-33], as well as groundwater [34-36].

Characteristics of Glebokie Lake

Lake Glebokie is located in the north-western part of the city of Szczecin, *ca* 7 km from the city centre. It is a lake devoid of surface inlets and outlets (Table 1, Fig. 1). The drainage area of the lake is covered with urban sprawl - residential area Glebokie, with waste water system settled since 2010. Rain water from this area is draining directly into the lake.

Table 1

Morphometric characteristic of Glebokie Lake

Geographical coordinates	Latitude		53°28′18.7″N
	Longitude		14°29′07.8″E
Morphometric data			
Morphometric indicator	Units	Data on the year	
		before 1995[1)]	2013
Water level	[m asl]	17.5	19.0-19.4
Area	[10^4 m^2]	31	38[3)]
Capacity	[10^3 m^3]	751.2	-
Depth - max	[m]	5.0	6.0[3)]
Depth - average	[m]	2.4	-
Lenght max	[m]	1550	1690[2)]
Width max	[m]	300	324[2)]
Length of coastline	[m]	3950	4430[2)]

1) [37], 2) Planimetry on Google Earth Pro, 3) [12]

In close proximity of the lake (distance of 1.5 km), a deep water intake is located in Pilchowo, supplying drinking water for the city of Szczecin agglomeration. The intake is operating since 1929. The aquifers in this area are located at 20 to 50 m depth below the soil level [12, 13].

Due to overexploitation of underground water at Pilchowo, a sizable depression hollow was created in the alimentary zone of the intake station. The Glebokie Lake is part of the depression hollow, and due to the inadequate water supply to the aquifers the lake was deprived of nearly 1/3 of water volume in the years 1975-1976. To save the lake ecosystem, as much as 400 thousands m^3 of water from the urban plumbing system was pumped into the lake. The amplitude of water level in the lake reached *ca* 2.4 m in 1987-1988. At that time, the attempt to restore the lake water balance included supplying water from a stream Osowka and a Mala Gunica River.

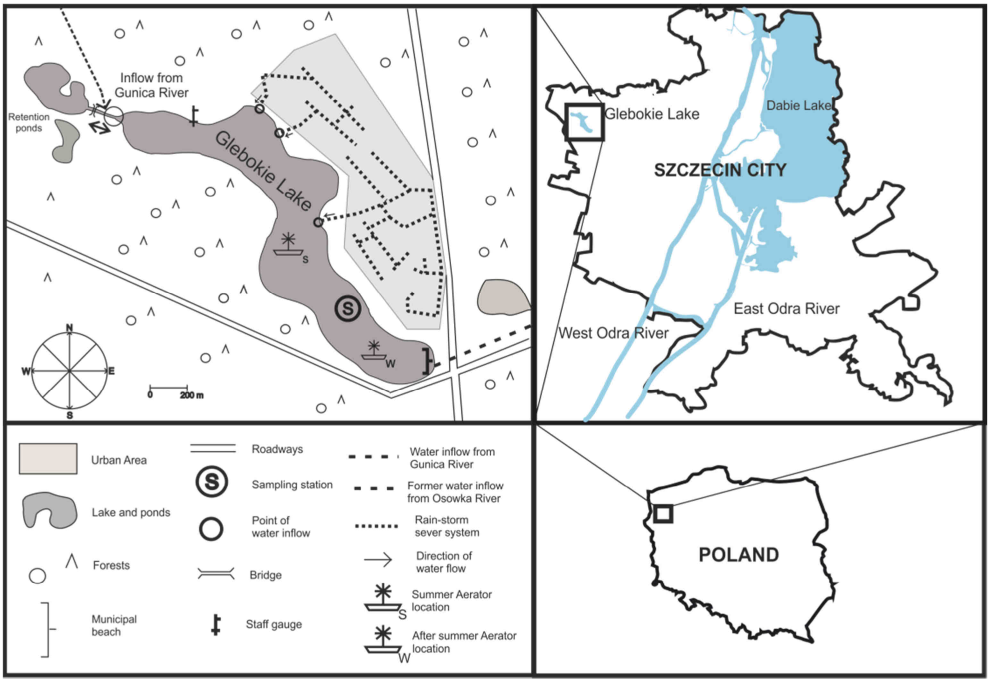

Fig. 1. Glebokie Lake in Szczecin City (NW-Poland)

The stabilization of water level in the Glebokie Lake was effectively solved only in 2004 by construction of a pumping station and an 9 km long pipeline to transfer water to the lake from the Gunica River. The water permit allows for a daily transfer of 16 850 m^3 of water from the Gunica River to the lakes Glebokie and Bartoszewo from November till April. In practice, the water is pumped twice a year: in November and in April - in the months of particularly high abundance of water the Gunica River. To stabilize water level in the lake in summer, an additional hydrotechnical construction was installed in the northern edge of the lake. It is pumping water to the lake up to the ordinate 19.4 m and simultaneously supplies water into the nearby retention ponds (Fig. 1) from which water flows into the Glebokie Lake when the ordinate declines to 19.0 m.

Water quality in the Gunica River is not very good as the river drains from the Swidwie Lake and the surrounding broads and swamps, a strict nature reserve for waterfowl; it is loaded with organic matter including organic compounds of phosphorus and nitrogen [38, 39]. In 2012 and 2013, *ca* 15% of the lake volume (under the ordinate 19.4 m) was supplied each time during the spring and autumnal pumping.

Recently, the Glebokie Lake remains under considerable anthropogenic pressure considering the supply of water from the river Gunica, containing large amounts of suspended and dissolved organic matter, surface run-off, rain water sewerage input and the municipal recreation spot (city beach) functioning in the lake from 15 May till 31 August, *eg* in 2013 the beach was visited by over 70 000 people, and between 10-27 July 2008 the beach was closed due to microbial pollution.

Since 2008, a wind operating aerator was installed in the lake, providing oxygen to constantly hypoxic and temporarily anoxic near bottom water. Anoxia formed in the lake in recent years, particularly intensive in summer. The aerator is operating continuously, except when the ice cover appears on the lake [13]. The aerator was also used to discharge a coagulant PIX (acidic solution of $FeSO_4$) into the near bottom water. Before 2008 the concentration of Fe were ≤ 0.01 Fe $\cdot$ dm^3 according to our earlier studies. Ferrous sulphate binds phosphorus from the near bottom water forming insoluble phosphates which become buried in the sediments.

According to the aerator producer [40], in such shallow lakes as the Glebokie Lake the coagulant dose of 5-15 kg per 1 ha is sufficient. Appearance and functioning identical aerator has been already shown [41]. The removal of excess phosphate was supposed to diminish strong phytoplankton blooms occurring in the lake [12]. However, as confirmed by a study conducted in 2010, the applied measures - water aeration and coagulant supply - did not bring any improvement in oxygen situation of the lake water [12, 13]. There are stable phytoplankton and zooplankton communities in the lake, with taxonomic structure and abundance resembling those of dam reservoirs in Poland. Past 2009, the lake was stocked with fry a number of times and there are at least 14 fish species inhabiting, especially dominate (by number and weight of caught fish) species: *Abramis brama*, *Rutilus rutilus* and *Scardinius erythrophthalmus* and (derived from artificial stocking), *Esox lucius* and *Sander lucioperca*. The composition of the fish fauna is determined mainly to the needs of anglers [42]. The ecological status of the lake is assessed moderate by environmental monitoring services [43].

Material and methods

From August 2012 to August 2014 - 25 months, a study was conducted in Glebokie Lake (Szczecin) concerning measurement of 19 water quality indices, that is temperature (TEMP), chlorophyll *a* content (Chl *a*), dissolved oxygen (DO), water saturation with oxygen (WS), chemical oxygen demand (COD-Cr), biochemical oxygen demand (BOD_5), ammonia-nitrogen ($N\text{-}NH_4$), nitrate-nitrogen ($N\text{-}NO_3$), nitrite-nitrogen ($N\text{-}NO_2$), total nitrogen (TN), soluble reactive phosphates (SRP), total phosphorus (TP), calcium (Ca^{2+}), total hardness (TH), chloride (Cl^-), sulphate (SO_4^{2-}), hydrocarbonate (HCO_3^-) - determined as total alkalinity and total iron (Fe_{tot}). Water samples were collected at a dedicated sampling station (Fig. 1) from 0.5 m depth; sampling was completed once a month (±2 days) in the 25 months period. Sampling, sample processing and analytical methods were compatible with APHA [44].

The obtained results, except for dissolved oxygen data, were subjected to multivariate statistical analyses: cluster analysis (CA), principal component analysis/factor analysis (PCA/FA) and discriminant analysis (DA).

Cluster Analysis (CA) groups the variables into clusters on the basis of similarities and dissimilarities between different classes. The results of CA showed as dendrogram are a useful tool helping in interpret the data [19, 20, 22-25, 30, 33, 35].

Principal Components Analysis (PCA) transforms the original variables into a smallest set of independent variables (principal components - PC's), which linearly combine with observable variables. These technique provides information on the most meaningful parameters, which describe whole data set with minimum loss of original information. It helps in pattern recognition that attempts to explain the variance of set of inter-correlated variables and transforming into a smaller set of independent variables [20, 21, 30, 31, 33].

Factor Analysis (FA) allows the emergence of less dimensional (compared to PCA) linear structures from the original database. In the assumption FA reduces contribution of less relevant variables obtained during the extraction of data by the PCA. The main difference between the PCA and FA is that the FA allows the expression of the measured values as a combination of factors and the equation includes a term, and thus obtained *varifactors* (factors after varimax rotation) may comprise previously unobservable hidden variables [18, 20, 30, 31, 35, 36].

Discriminant Analysis (DA) determines statistically significant independent variables that discriminate between naturally occurring groups. It builds a linear combination of variables (equation) which constructs a discriminant function (DF) for each group. DA can identify the most important discriminant water quality variables for each defined group.

The set of experimental data was performed with z-standarization method, *ie*: $z_i = \left(\frac{x_i - \bar{x}}{SD}\right)$ - for the *i*-th value of the parameter x, where: $\bar{x}$ - the average value of x, SD - standard deviation prior to all analyses - to avoid misclassification due to wide differences in data units and dimensionality; only DA was carried out with raw data [14, 15]

Prior to the analyses the data sets were tested for normal distribution with Kolmogorov-Smirnov test applicable for small samples [26, 30]. The testing produced positive result - the data were normally distributed.

Statistical analyses were done using commercial software STATISTICA 10.0PL and STATGRAPHICS Centurion XVI.

Results and discussion

The obtained results are presented in Figures 2 and 3 - as graphs of water quality indices in time and in Table 2 as statistical characteristics of data sets.

The collected data can be analyzed descriptively, as performed in this study as well as in overall practice [45, 46] and - with chemometric methods as presented in these paper.

Based on the data shown in Figures 2 and 3 water column of Glebokie Lake can be characterized, with seasonal changes in water temperature in range from approx. 0°C (January-February) to approx. 25°C (June-July), which is typical for the temperate climate zone accompanied with changes of surface water quality indices [47], and in particular: changes in the concentrations of chlorophyll *a* from 20 to more than 70 $\mu g \cdot dm^{-3}$ in periods of April-May, September-November which indicates that the water of the Lake were constantly in phytoplankton - blooms-state [48] - apparently related to the Gunica river inflows. Surface water in the study period were always unsaturated (less than 100% of saturation) while drops to 20% of water saturation occurred in summer (June-July) - during swimming season. This demonstrates the extensive overlap of processes of decomposition of organic matter in the water column at this time.

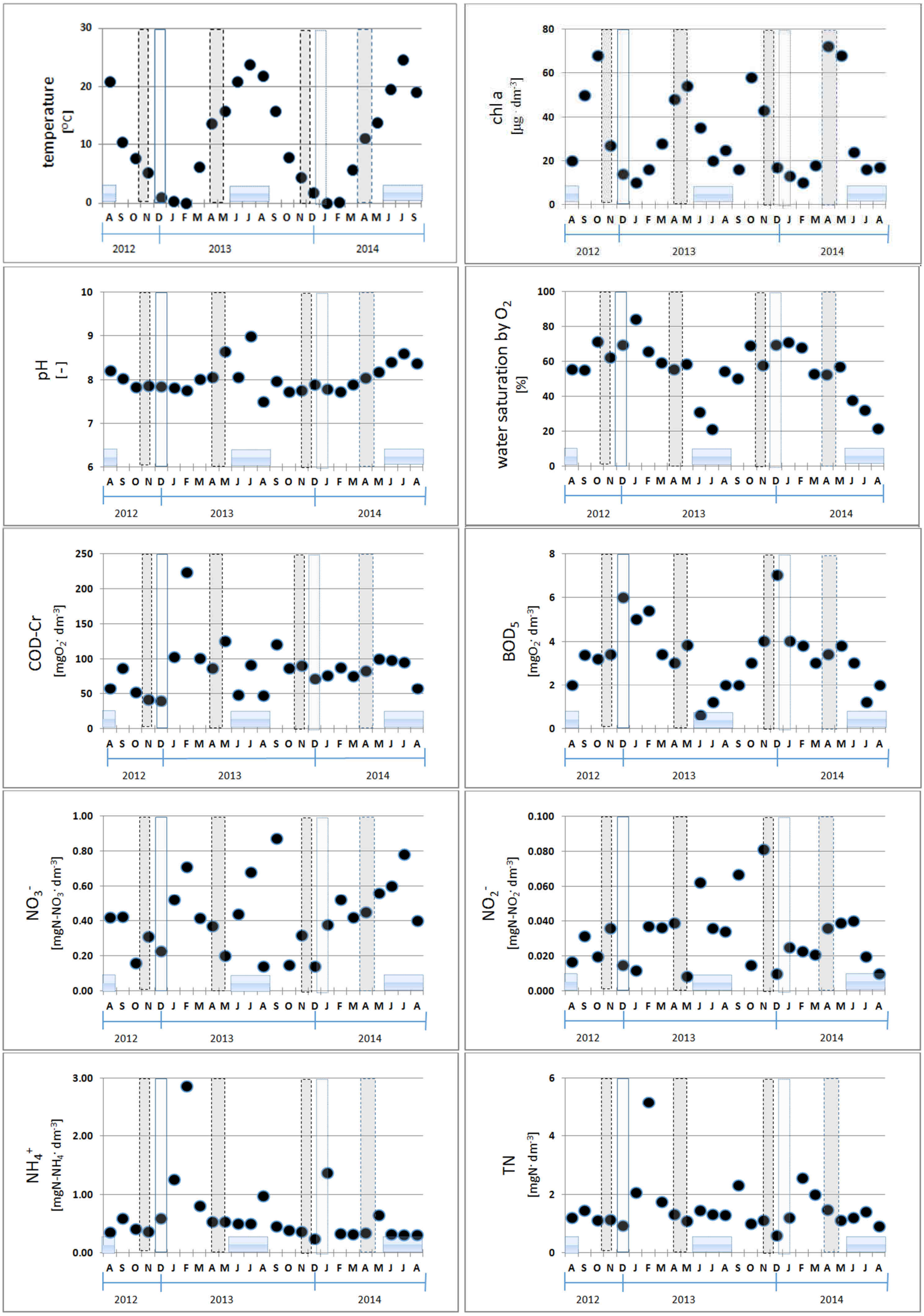

Fig. 2. Surface waters quality indices values of Glebokie Lake in years 2012-2014. Explanations: [dotted box] - ice cover presence; [blue box] - swimming season; [dashed box] - water transfer from Gunica river

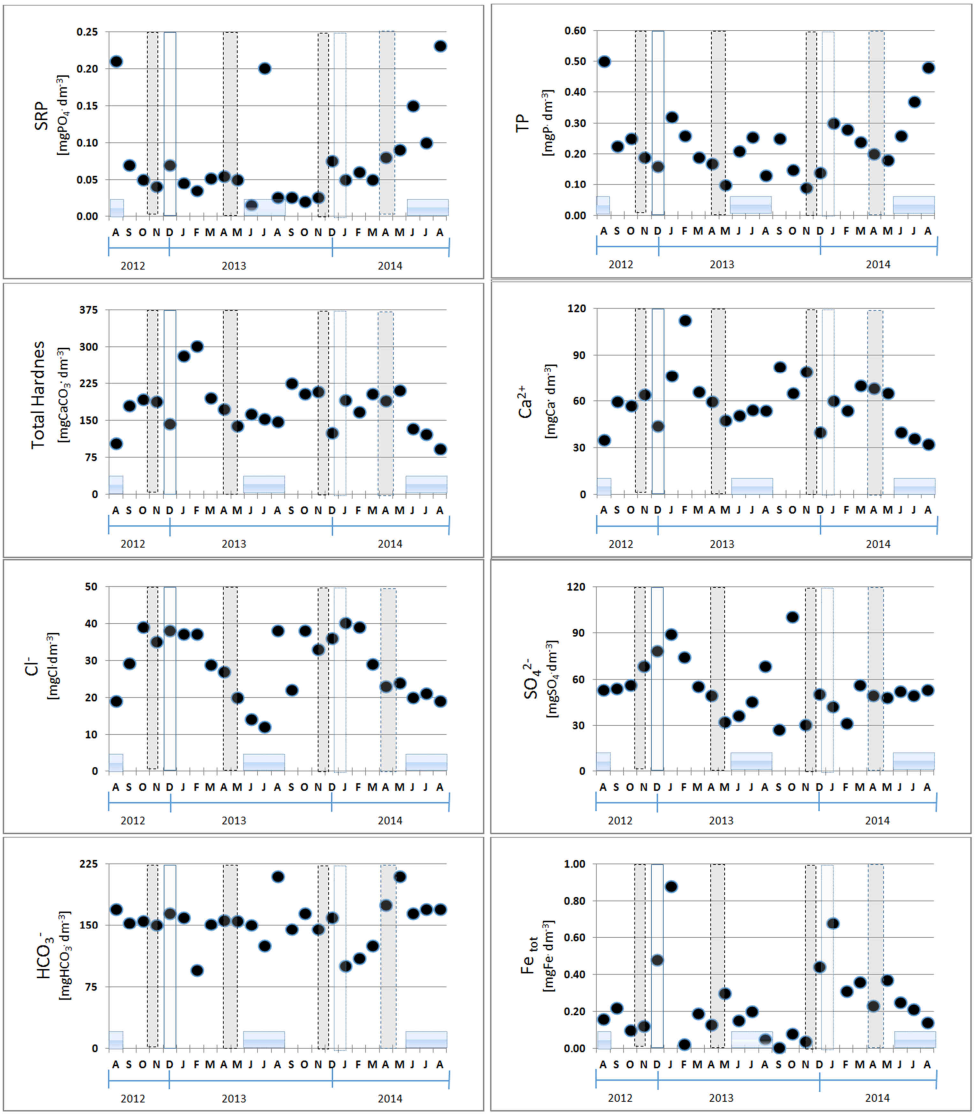

Fig. 3. Surface waters quality indices values of Glebokie Lake in years 2012-2014. Explanations: - ice cover presence; - swimming season; - water transfer from Gunica river

At the same time Glebokie waters were characterized by a stabilized pH values (approx. 7.00-8.50); only incidentally pH were slightly higher. The amount of dissolved and suspended organic matter varied by assessing the COD-Cr from about 50 to approx. 120 mg $O_2 \cdot dm^{-3}$. Very specific changes in BOD_5 indicate that the water from Gunica carried large amounts of biodegradable organic matter and microorganisms decomposing organic matter. The BOD_5 values always drastically decreased during the summer (municipal beach impact?). The concentration of nitrogen compounds (NO_3, NO_2, NH_4 and

TN) changed very irregularly - increased values observed after inflows of Gunica waters. Similarities of changes of SRP and particularly TP concentrations are noticed, though relationship was more noticeable. TH and Ca^{2+} - are clearly stabilized. The concentration of Cl^{-} - decreased after the withdrawal of ice from the Lake (due to the use of NaCl and $CaCl_2$ to remove freezing on roads), reaching lowest concentrations during the summer, and SO_4^{2-} concentrations of changed irregularly - probably occurring due to acid rain.

Table 2

Statistical characteristics of data sets for Glebokie Lake in study period 2012-2014

Water chemistry indices	Units	Descriptive Statistics	Value
Temperature	[ºC]	Mean ± SD Range	11.0 ± 8.3 0.2-24.8
Chlorophyll *a*	[μg Chl *a* · dm^{-3}]	Mean ± SD Range	31 ± 20 10-72
pH	[-]	Mean ± SD Range	8.03 ± 0.34 7.50-8.98
Water saturation by O_2	[%]	Mean ± SD Range	55 ± 16 21-84
COD-Cr	[mg O_2 · dm^{-3}]	Mean ± SD Range	86 ± 37 40-223
BOD_5	[mg O_2 · dm^{-3}]	Mean ± SD Range	3.3 ± 1.5 0.6-7.0
NO_3^-	[mg N-NO_3 · dm^{-3}]	Mean ± SD Range	0.42 ± 0.20 0.14-0.87
NO_2^-	[mg N-NO_2 · dm^{-3}]	Mean ± SD Range	0.03 ± 0.02 0.01-0.08
NH_4^+	[mg N-NH_4 · dm^{-3}]	Mean ± SD Range	0.57 ± 0.53 0.24-2.85
TN	[mg N · dm^{-3}]	Mean ± SD Range	1.44 ± 0.85 0.30-5.14
SRP	[mg PO_4 · dm^{-3}]	Mean ± SD Range	0.07 ± 0.06 0.02-0.23
TP	[mg P · dm^{-3}]	Mean ± SD Range	0.24 ± 0.10 0.09-0.50
TH	[mg $CaCO_3$ · dm^{-3}]	Mean ± SD Range	178 ± 49 90-301
Ca^{2+}	[mg Ca · dm^{-3}]	Mean ± SD Range	59 ± 18 32-112
Cl^-	[mg Cl · dm^{-3}]	Mean ± SD Range	29 ± 9 12-40
SO_4^{2-}	[mg SO_4 · dm^{-3}]	Mean ± SD Range	54 ± 18 27-100
Alkalinity	[mg HCO_3 · dm^{-3}]	Mean ± SD Range	153 ± 27 95-210
Fe_{tot}	[mg Fe · dm^{-3}]	Mean ± SD Range	0.22 ± 0.18 0.01-0.88

The concentration of HCO_3^- were stabilized with some exceptions. Persistence of stable concentrations of Ca^{2+}, HCO_3^- indicates that the pH of the water was stabilized by a carbonate buffer respondents effectively adjusting the acidity of the water, due to the presence of $CaCO_3$ in suspension and bottom sediments [49]. Specifically they changed while the concentration of Fe_{tot} - usually increased when lake was frozen, which seems to indicate a release of Fe^{2+} under anoxic conditions from bottom sediments. The Fe_{tot}

concentration also increased, but in lesser extent - for subsequent inflows of water from the Gunica River.

Assessing the trophic status of examined waters according to the procedure given by Carlson, based on the concentration of total phosphorus and chlorophyll in surface waters - it was determined that the water had the status eutrophic/hypertrophic, regardless of the season [50]. Similar conclusions could be found, based on research results of Glebokie Lake in years 2008-2010 - in paper [13].

In order to determine the factors that had a statistically significant impact on the water quality of Glebokie lake over the study period - chemometric analysis of the data collected were conducted as planned.

Cluster analysis

Cluster analysis was conducted to discern similarities between the measured water quality indices (Figs. 4 and 5). The Ward's method of agglomerative hierarchical clustering was used with squared Euclidean distance as the objective function [18, 20, 22, 23, 28, 29].

Water quality indices were grouped into several clusters showing similar level of variability (Fig. 4). The main group is formed by parameters characterizing concentrations of certain mineral substances (Cl^-, SO_4^{2-}, Fe_{tot}), water saturation as well as BOD_5 content. This observation indicates significant role played by processes of oxygen enrichment and biochemical degradation of organic matter in the lake ecosystem as well as by the dissolved $FeSO_4$.

The second major group comprises the indices characterizing the pool of organic and biogenic substances *ie* NO_3^-, NO_2^-, NH_4^+, TN, SRP, TP and COD-Cr. This indicates the strong anthropopressure regarding nutrient supply to the lake.

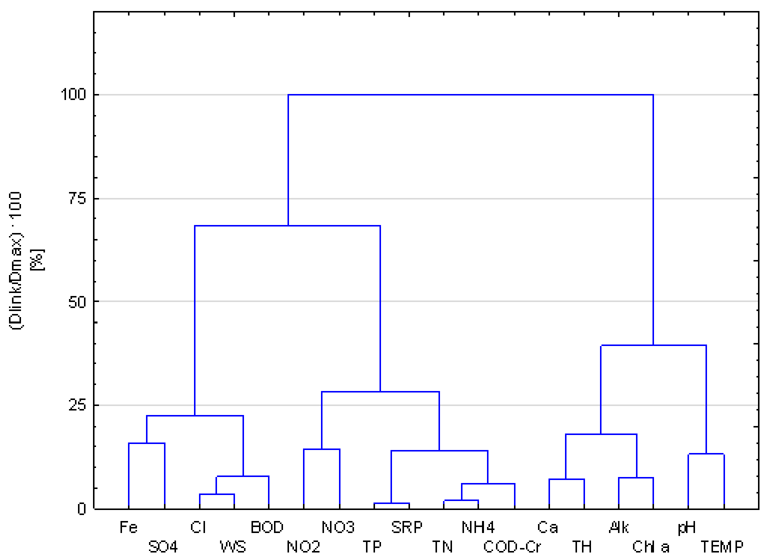

Fig. 4. Cluster analysis results of water quality indices in sampling months

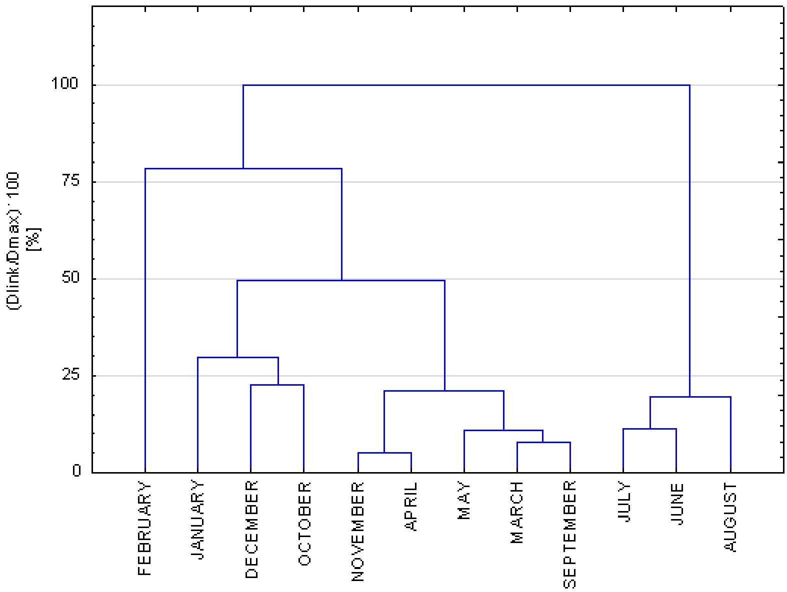

Fig. 5. Cluster analysis results on water quality indices

The third main group contains TEMP, pH, HCO_3^-, Ca^{2+}, TH and chlorophyll *a*, indicating the obvious relationship between water temperature and phytoplankton development and the sliding of the acid-base balance and also dissolution of $CaCO_3$.

The temporal agglomeration produced some unexpected months' groups (Fig. 5). The first main group (I) discerned consisted of month with daily mean of air temperature over 18°C, that is June, July and August. In this period the anthropogenic pressure is increasing due to recreation in the lake, and also the biological and microbiological processes (assimilation and dissimilation) become more intensive.

The second group (II) included months with lower daily mean temperature (< 15°C) and this is further divided into a number of subgroups: March, May and September in one subgroup and April and November - the months when water from the river Gunica was transferred to the Glebokie Lake in the second. The third subgroup (III) contains January, December and (surprisingly) October. February which is usually the coldest month in a year when ice cover occurs in the lake, forms a separate subgroup.

Principal Component Analysis/Factor Analysis

Principal Component Analysis provides information on the most important water quality indices that describe the entire data set by performing data reduction with minimal loss of original information carried by the data [21, 22, 24, 28, 29, 45].

The principal component analysis (PCA) produced 21 principal components; where 5 of them were characterized by eigenvalue exceeding 1 (Fig. 6, Table 3) [21, 22, 24, 28, 29, 34, 45]. PC1, which described 34.7% of variability did not show significant correlations with the analyzed water quality indices (values in range 0.35>x<–0.35). PC2, which characterized 21.4% of variance showed positive correlations with COD-Cr, NO_3^-, NH_4^+, TN and SRP - suggesting a strong influence of sewage inflow of anthropogenic origin. Also PC3 (13.6% of total variance) was positively correlated with Chl *a* and NO_2^- and negatively with SRP and Fe_{tot} while PC4 (7.8% of the total variance) showed only negative correlation with Chl *a*, SRP, TP and alkalinity - showing a big influence of phytoplankton blooms (multiplication phytoplankton biomass). The last principal component - PC5 - described 6.1% of the total variance and was strongly positively correlated with SO_4^{2-} and Fe_{tot} and negatively with pH. PC5. The analysis pointed out to considerable influence exerted on the Glebokie Lake by the incorporated coagulant ($FeSO_4$).

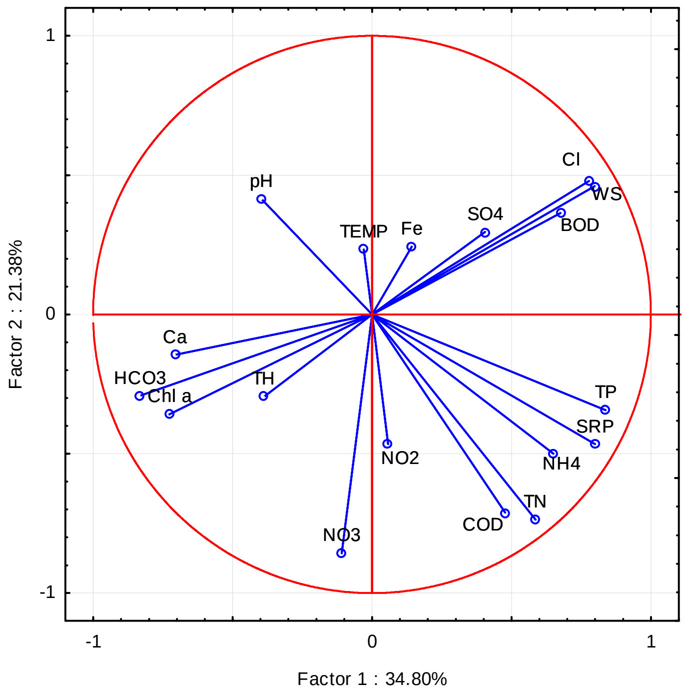

Fig. 6. The graph of factor coordinates for water quality indices

PCA analysis indicated that 12 out of 18 water quality indices are characterised by statistically significant variability, meaning that the conditions in the Lake Glebokie are extremely changeable.

To discern the most important water quality indices which determined ecological status of the Glebokie Lake in the study period and in particular seasons (winter, spring, summer and autumn) the measurement data were subjected to factor analysis (FA), using PCA as data extraction method with subsequent Varimax rotation (Table 4).

Taking into account the classification system correlation matrix between the different varifactors - a further indices of water quality proposed by [36] were considered relevant only strong correlation, *ie* those which charge is in the range of from 0.75 to 1.00 [18-20, 25, 27-29, 34, 35, 45].

FA for the entire study period emerged 5 significant VF (describing a total of 83.6% of the variance), which eigenvalues - are greater than 1.

Table 3

Factor loadings for PCA

	PC1	PC2	PC3	PC4	PC5
TEMP	0.3327	0.1487	0.1152	–0.2626	0.1710
Chl *a*	0.0120	–0.1188	**0.3943**	**–0.4251**	–0.2446
pH	0.2903	0.1825	–0.1102	–0.1435	**–0.3895**
WS	–0.3190	–0.2346	–0.0670	0.0153	–0.1017
COD-Cr	–0.1909	**0.3624**	–0.0516	–0.1616	–0.2122
BOD_5	–0.2697	–0.1854	–0.1687	0.0536	–0.3117
NO_3	0.0438	**0.4367**	–0.1057	0.0480	–0.1496
NO_2	–0.0226	0.2370	**0.4667**	0.1775	0.0380
NH_4	–0.2600	**0.3548**	–0.1410	–0.2636	0.2037
TN	–0.2344	**0.3753**	–0.0974	–0.1169	0.1657
SRP	0.2826	**0.7376**	–0.3264	**–0.5421**	–0.0034
TP	0.1552	0.1502	**–0.4290**	**–0.7974**	0.2506
Ca	–0.3347	0.1750	0.0716	–0.1399	–0.1081
TH	–0.3195	0.2372	0.1565	–0.0783	–0.0216
Cl	–0.3108	–0.2438	–0.0629	0.1365	0.2188
SO_4	–0.1619	–0.1511	–0.2506	–0.2732	**0.3402**
Alk	0.1581	–0.2109	0.1322	**–0.5290**	0.0890
Fe	–0.0567	–0.1242	**–0.3473**	–0.1619	**0.5171**
Eigenvalue	6.2633	3.8485	2.4402	1.3967	1.1047
% Total variance	34.79	21.38	13.55	7.75	6.13

Table 4

Factor loadings after Varimax Rotation (Factor Analysis)

	VF1	VF2	VF3	VF4	VF5
TEMP	**0.8714**	–0.2130	0.0884	–0.3274	0.1398
Chl *a*	0.0741	–0.0733	**0.8569**	–0.0302	0.0842
pH	**0.8705**	–0.0934	–0.0281	0.2813	–0.1888
WS	**–0.8457**	0.1377	0.1268	0.3237	0.1309
COD-Cr	0.0747	**0.8860**	–0.0017	0.1308	–0.1368
BOD_5	–0.6775	0.1418	0.0371	0.5367	–0.0067
NO_3	0.5246	0.5775	–0.2986	–0.0082	–0.3212
NO_2	0.0737	0.2917	0.3056	–0.6128	–0.4869
NH_4	–0.1769	0.8489	–0.1412	–0.0139	0.3042
TN	–0.0640	**0.9402**	–0.2264	–0.1221	0.0671
SRP	0.6788	–0.2746	–0.4296	0.2186	0.1291
TP	0.4236	–0.0190	–0.7364	0.0845	0.1893
Ca	–0.4255	**0.8046**	0.1995	0.0514	–0.0340
TH	–0.3779	**0.8435**	0.1932	–0.1416	–0.1139
Cl	**–0.9302**	0.0569	–0.0659	0.0472	0.2175
SO_4	–0.3084	0.1713	–0.0274	0.1959	**0.8259**
Alk	0.2887	–0.3934	0.5024	–0.0092	0.5285
Fe	–0.0699	0.0041	–0.0259	**0.8327**	0.0831
Eigenvalue	6.26	3.84	2.44	1.39	1.10
Variance	34.79	21.38	13.57	7.75	6.17
Cumul. %	34.79	56.17	69.73	77.49	83.62

Table 5 shows that 11 of the 18 surveyed of the water quality indices has a significant contribution defined in this analysis of volatility, particularly strong positive correlations showed Chl *a*, temperature, pH, and thus parameters characterizing the processes of proliferation of biomass phytoplankton, COD-Cr, TN, TH, Ca^{2+}, which variation is associated primarily with the inflow of water from the river Gunica rich in organic matter and the suspension, and - SO_4^{2-} and Fe_{tot}, which means the existence of persisting coagulant ($FeSO_4$) impact on the ecosystem of the Glebokie Lake.

Table 5

Results of discriminant analysis calculations

Criterion	**I**			**II**			**III**			**IV**		
Indices in equation	Wilks' λ	Partial Wilks' λ	Tole-rance	Wilks' λ	Partial Wilks' λ	Tole-rance	Wilks' λ	Partial Wilks' λ	Tole-rance	Wilks' λ	Partial Wilks' λ	Tole-rance
TEMP	**0.0094**	**0.1843**	**0.0418**	**0.0843**	**0.1733**	**0.4651**	-*	-*	-*	0.1345	0.1858	0.0211
Chl *a*	**0.0065**	**0.4028**	**0.0722**	**0.0392**	**0.3727**	**0.6430**	-*	-*	-*	0.0794	0.4532	0.0276
pH	-*	-*	-*	-*	-*	-*	-*	-*	-*	-*	-*	-*
WS	0.0066	0.3868	0.0544	0.0177	0.6223	0.4657	-*	-*	-*	0.0747	0.4941	0.0261
COD-Cr	-*	-*	-*	-*	-*	-*	-*	-*	-*	**0.0021**	**0.0954**	**0.0177**
BOD_5	**0.0019**	**0.0216**	**0.0595**	-*	-*	-*	-*	-*	-*	-*	-*	-*
NO_3	0.0065	0.3976	0.0167	**0.0180**	**0.1117**	**0.5115**	0.2931	0.2857	0.0500	**0.0665**	**0.3804**	**0.0119**
NO_2	0.0085	0.5380	0.0197	-*	-*	-*	-*	-*	-*	0.0811	0.4397	0.0186
NH_4	**0.0026**	**0.1019**	**0.0172**	-*	-*	-*	**0.1893**	**0.1777**	**0.0439**	**0.0074**	**0.1366**	**0.0162**
TN	-*	-*	-*	-*	-*	-*	-*	-*	-*	-*	-*	-*
SRP	-*	-*	-*	-*	-*	-*	-*	-*	-*	0.0585	0.686	0.0340
TP	**0.0026**	**0.1937**	**0.0332**	**0.0229**	**0.1363**	**0.5653**	**0.1149**	**0.2982**	**0.0327**	**0.0608**	**0.1527**	**0.0322**
Ca	0.0066	0.6864	0.0100	-*	-*	-*	-*	-*	-*	0.0873	0.3946	0.0041
TH	-*	-*	-*	-*	-*	-*	-*	-*	-*	0.0709	0.5315	0.0057
Cl	-*	-*	-*	0.0175	0.6330	0.3433	-*	-*	-*	0.0638	0.6135	0.0214
SO_4	**0.0014**	**0.0993**	**0.0319**	-*	-*	-*	-*	-*	-*	-*	-*	-*
Alk	-*	-*	-*	-*	-*	-*	**0.1475**	**0.4481**	**0.0611**	-*	-*	-*
Fe	0.0060	0.4600	0.0631	-*	-*	-*	-*	-*	-*	-*	-*	-*

Wilks 'λ - standard statistics used to determine the statistical significance of the current discriminative power of the model (range from 1 to 0, where 0 indicates perfect discriminatory power); Partial Wilks' λ - defining the specific contribution of the variable to discrimination group (the smaller the value, the greater the discriminatory power of the variable); Tolerance - determines the redundancy of a given variable, defined as $1 - R^2$ [26, 32].

* no statistical significance

The results of the factor analysis failed to cut the number of water quality indices that have changed in a statistically significant degree - this analysis has emerged as many as 11 out of 18 water quality indices as statistically significant.

Discriminant analysis

Discriminant analysis were conducted assuming 4 discriminant criteria: seasonality was the first criterion, the second criterion was formulated basing on CA analysis showing similarities in parameter variability regarding sampling date, *ie* on the month of sampling. Glebokie Lake supplementing with riverine water from the Gunica River in April and November was chosen as the third criterion and the fourth criterion was the bathing season.

The analysis was done using forward stepwise method and resulted in 4 separate formulas, containing different number of water quality variables depending on the assumed criterion; 11 variables were included for the I criterion, 6 - for the II criterion, 4 - for the III criterion and 12 for the IV criterion (Table 5). Only parameters characterized by partial Wilks' $\lambda < 0.75$ were taken into consideration [18, 20, 25, 26, 32].

Discriminant analysis produced 4 orthogonal functions for each of the assumed criteria, each having a cumulative variance of 97, 93, 95 and 88% - respectively.

The results of partial Wilks' λ (Table 5) indicate that ammonia, BOD_5, temperature, TP and SO_4^{2-} are the most important variables in the first discriminant criterion. It points to the overlap of processes of assimilation, dissimilation, and a significant decomposition of organic matter of anthropogenic origin. In the II discriminant criterion - temperature, chlorophyll *a*, TP and NO_3^- concentrations showed the strongest discriminant influence - indices associated with assimilation and dissimilation process. In the case of the II criterion - TP, NH_4^+, NO_3^- and alkalinity, while in the IV criterion - COD-Cr, NO_3^-, NH_4^+ and SRP - showed the most discriminant power in the calculated models. These parameters indicate the increased inflow of phosphorus compounds and the decomposition of organic matter (in the case of the III criterion) and the very significant impact of anthropopression on the ecosystem (criterion IV).

The analysis indicated water quality parameters of the Glebokie Lake which variability was the most affected by pressure factors - seasonality, water supply from the river Gunica: BOD_5, COD-Cr, SO_4^{2-}, TP, NO_3^- and NH_4^+. The BOD_5 and COD-Cr presence among the most affected variables was also indicative of additional pressure factor influencing water quality in the Glebokie Lake - the shifting balance between assimilation and dissimilation processes.

Conclusions

1. Subsequently to regulation of hydrological conditions in 2004 and counterbalance its negative water balance, Glebokie Lake turned into an open system and during the study period (2012-2014) remained in the eutrophic-hypertrophic state with specific periodic changes of examined water quality indices.
2. Using multiple statistical analysis it was pointed out that water quality in the Glebokie Lake is mainly affected by:
   a) seasonal variability - related to climatic rhythm of biological processes in the ecosystem,
   b) intermittent - twice a year: in April and November - supply of water from the Gunica River, rich in suspended and dissolved organic matter,
   c) increased anthropogenic pressure incidents in summer (populated urban bathing spot),
   d) lake ecosystem enrichment in iron compounds, incorporated to the ecosystem as a coagulant and organic matter oxygenation activator in water and sediments in 2008-2009.
3. The chemometric analyses applied to determine factors influencing water quality in the Lake Glebokie proved to provide satisfactory results despite the short data series.

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