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WATER CHEMISTRY OF LAKE GIŁWA

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Abstract

The study was carried on Lake Giłwa (100.8 ha, 9.4 m), in the drainage basin of the Giłwa and Pasłęka rivers. The data obtained in the study allowed the authors to classify Lake Giłwa as a water body belonging to the third stability degree according to PATALAS (1960). As evidenced in the study, Lake Giłwa is a highly eutrophic reservoir. The lake waters were characterized by a high content of nutrients, up to 1.40 mg $P \cdot dm^{-3}$ and 12.47 mg $N \cdot dm^{-3}$. The high fertility of the lake was also exhibited by the values of BOD_5 reaching 7 mg $O_2 \cdot dm^{-3}$, chlorophyll *a* content (73 $mg \cdot m^{-3}$) and low transparency – 0.7 m. In the peak of the summer, the stagnation oxygen profile is represented by a clinograde curve typical for eutrophic lakes, while carbon dioxide distribution in the water column is shown by a „reverse" clinograde curve, also typical for fertile reservoirs.

The study has revealed that the water in Lake Giłwa is well buffered, as shown by the alkalinity values, 2.5-5.0 mval dm^{-3}. Total hardness of the reservoir water varied from 157.1 to 278.8 mg $CaCO_3 \cdot dm^{-3}$, which is typical of hard water. The hardness was conditioned mainly by the calcium content. With the River Giłwa, the lake receives wastewater from the wastewater treatment plant in Gietrzwałd, which is manifested, for example, by the high values of electrolytic conductivity (321-476 $\mu S \cdot cm^{-1}$), indicating the degree of mineral pollution of the lake. Despite the wastewater input, the amount of chlorides is rather low, 20 mg $Cl \cdot dm^{-3}$ at the most.

Key words: lake, nutrients, preliminary production, Secchi disc visibility, eutrophication.

CHEMIZM WÓD JEZIORA GIŁWA

Abstrakt

Badaniami objęto jezioro Giłwa (100,8 ha, 9,4 m) położone w dorzeczu Giłwy-Pasłęki. Pod względem dynamiki wód jest to zbiornik o III stopniu statyczności wg PATALASA (1960). Badania chemiczne wód wykazały, iż jezioro Giłwa jest zbiornikiem silnie zeutrofizowanym. W jego wodach stwierdzono bardzo wysoką zawartość związków biogenicznych – 1,40 mg

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$P \cdot dm^{-3}$ i 12,47 mg $N \cdot dm^{-3}$. O dużej żyzności jeziora świadczyły także wartości BZT_5, dochodzące do 7,0 mg $O_2 \cdot dm^{-3}$, ilość chlorofilu *a* (ok. 73 $mg \cdot m^{-3}$) i niska przezroczystość wody – 0,7 m. W szczytowym okresie lata zawartość tlenu w wodzie obrazowała krzywa klinogradowa, typowa dla jezior eutroficznych, zaś rozkład dwutlenku węgla w słupie wody miał kształt odwrotnej klinogrady, co również jest typowe dla jezior żyznych.

Badania wykazały, że wody jeziora Giłwa są dobrze zbuforowane, o czym świadczyły wartości alkaliczności od 2,5 do 5,0 mval dm^{-3}. Twardość ogólna wód tego akwenu zmieniała się od 157,1 do 278,8 mg $CaCO_3 \cdot dm^{-3}$, co pozwala określić jego wody jako twarde. O twardości wód decydowała głównie zawartość wapnia. Za pośrednictwem rzeki Giłwy do jeziora doprowadzane są ścieki z oczyszczalni ścieków w Gietrzwałdzie, co uwidacznia się m.in. w wysokich wartościach przewodności elektrolitycznej (321-476 $\mu S \cdot cm^{-1}$), wskazującej na stopień zanieczyszczenia wód związkami mineralnymi. Pomimo dopływu ścieków, w wodach analizowanego zbiornika stwierdzono niewielką ilość chlorków – do 20 mg $Cl \cdot dm^{-3}$.

Słowa kluczowe: jezioro, związki biogenne, produkcja pierwotna, widzialność krążka Secchiego, eutrofizacja.

INTRODUCTION

Lake ecosystems undergo many complex chemical, physical and biological transformations (KUBIAK, TÓRZ 2005). Directions of these transformations are determined by water composition, which in turn is shaped by several factors. Among the most important ones are the geological structure and type of land use in a watershed, capacity of the soil sorption complex, weathering and solubility of minerals present in a watershed, atmospheric conditions, mixing of waters of different composition, and types of aquatic organisms (LETCHER et al. 2002, SCHOONOVER, LOCKABY 2006).

Although the chemical composition of water and trophic condition of most lakes located in Olsztyńskie Lakeland (Pojezierze Olsztyńskie) have been thoroughly analysed, there are still some lakes that have not been examined. Lake Giłwa in Rentyny is an example of a lake that has not been carefully studied until today. The literature data regarding this water body include morphometric properties and the temperature and DO measurements of September 1962. Therefore, it has been decided, for scientific as well as practical purposes, to elaborate on the collected material concerning the water chemistry of Lake Giłwa.

The main goal of this paper is to characterize the hydrochemical properties of Lake Giłwa and its trophic condition.

MATERIAL AND METHOD

Lake Giłwa is located approximately 20 km west of Olsztyn, in the Giłwa-Pasłęka Rivers drainage basin. The geographic coordinates are 53°46′2″ N and

20°14´2˝ E. To the north the lake is adjacent to the village Rentyny. The lake's axis runs from the north-west to the south-east. The surface area is 100.8 ha and the max. depth is 9.4 m (Table 1, Figure 1). Detailed morphometric parameters are given in Table 1.

Table 1

Detailed morphometric data and lake parameters
(after Institute of Inland Fisheries, Olsztyn, 1964)

Parameter	Values
Water table surface area (ha)	100.8
Maximum depth (m)	9.4
Mean depth (m)	3.7
Relative depth	0.0094
Depth index	0.39
Volume (thousand m^3)	3722.2
Maximum length (km)	2.2
Maximum width (km)	0.6
Elongation	3.7
Shoreline length of the lake bowl (km)	6.8
Shoreline development	1.95

The watershed draining directly to the lake of 1.66 km˛ surface area is dominated by forests (72.9%). The lake is intensively used for recreation; shores are occupied by recreation centres, camping fields, summer houses and bathing beaches.

Lake Giłwa is a flow-through reservoir. The Giłwa River enters the lake in the southern and flows out in the north-western part of the lake. The river feeds the lake with the treated wastewater discharged from the wastewater treatment plant in Gietrzwałd.

The analyses of the physicochemical properties of the water in Lake Giłwa were performed three times, on the following dates: November 27, 2007, April 29 and September 3, 2008. Water for analyses was taken from the deepest site in the lake, determined with the help of a bathymetric chart and GPS. Water samples were taken from 1 m depth under the water table and 1 m above the bottom. Simultaneously, temperature and DO were measured at every meter of the water column depth. Water transparency was measured with Secchi disc. Chemical analyses were done in accordance with the methods by HERMANOWICZ et al. (1999).

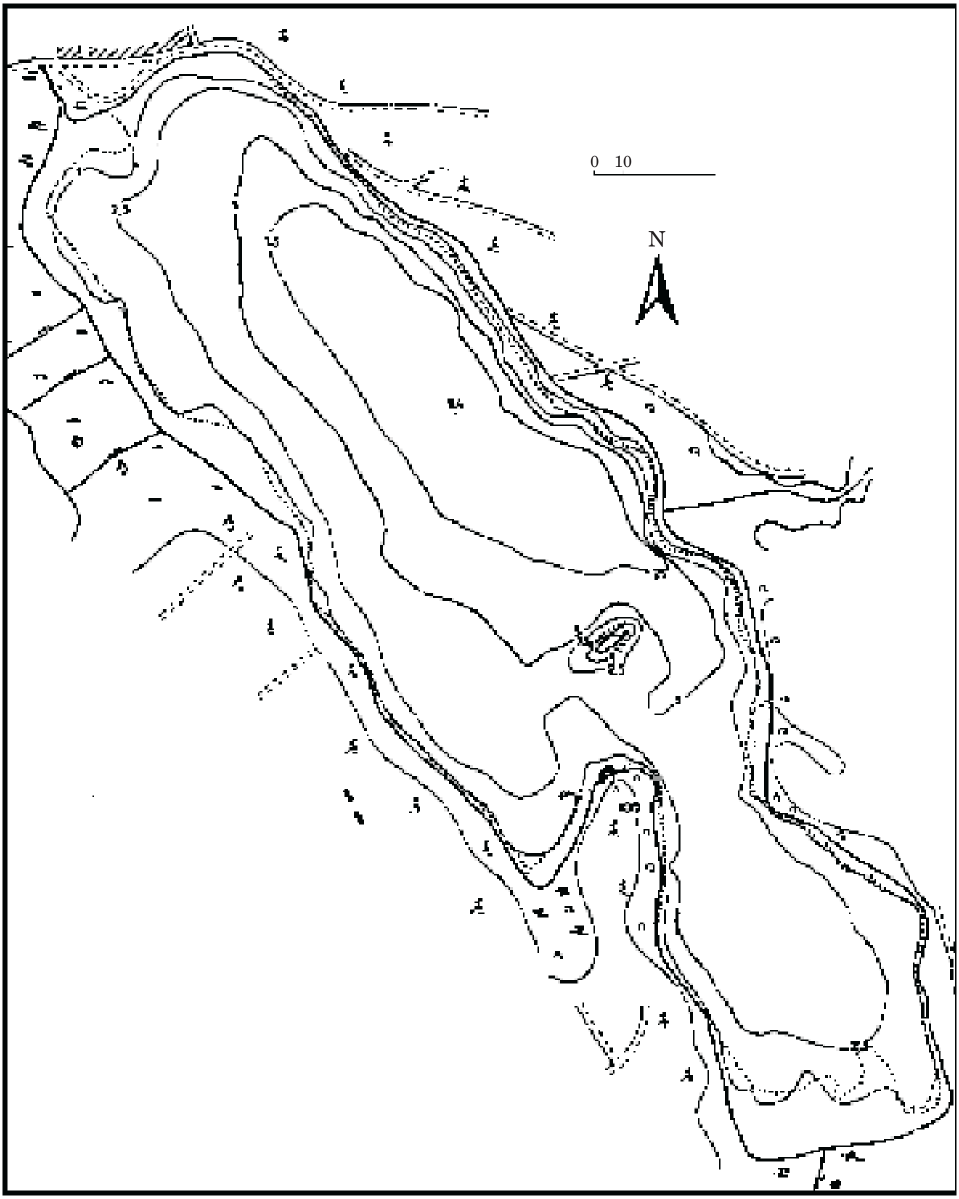

Fig. 1. Bathymetric map of Lake Giłwa

RESULTS AND DISCUSSION

Lake Giłwa is not very deep (9.4 m) but relatively large (100.8 ha). To the west, south and partly the east, the lake is surrounded by a forest, which considerably limits the inflow of water to the lake. Moreover, it is a flow-through reservoir, although this lake's characteristic is only weakly evident. Therefore, the intensity of water circulation is determined mostly by the lake's morphometric properties and exposure to wind. The first analysis (November) revealed that the whole water mass circulated at the temperature of 3.8°C. At the end of April, the water column was thermally stratified with a 6.0°C temperature difference between the surface and the bottom (Table 2). In early September, the lake stratified into a 6-m thick epilimnion and a metalimnion of the $3^{o}C \cdot m^{-1}$ gradient (Table 2). Based on the measurements taken on September 4, 1962 by Olszewski et al. (1978), the thermal variability in the water column was assessed as small, 15.7--14.5°C. The theoretical water mixing depth in Lake Giłwa, calculated after

Table 2

Thermal and oxygen profiles in lake Giłwa

Depth (m)	Autumn		Spring		Summer	
	temperture	oxygen	temperature	oxygen	temperature	oxygen
	(°C)	(mg $O_2 \cdot dm^{-3}$)	(°C)	(mg $O_2 \cdot dm^{-3}$)	(°C)	(mg $O_2 \cdot dm^{-3}$)
0	3.8	9.6	13.6	18.2	18.7	10.7
1	3.8	9.8	13.6	16.2	18.7	10.2
2	3.8	9.8	13.0	15.0	18.5	9.6
3	3.8	9.8	11.0	14.4	18.4	9.4
4	3.8	9.8	10.4	12.6	18.2	8.0
5	3.8	9.8	8.8	10.1	17.8	4.8
6	3.8	9.8	8.8	10.6	17.2	2.2
7	3.8	9.8	8.4	6.9	14.2	0.0
8	3.8	9.8	8.0	6.4	11.5	0.0
9	3.8	9.6	7.6	4.8	9.3	0.0

Patalas (1960) from the empirical equation E = 4.4 vD, is 5.2 m. The study shows that it is 0.8 m lower than the actual thickness of the epilimnion observed at the end of the summer. Taking into account the criteria given by Patalas (1960), Lake Giłwa can be classified as belonging to the 3rd static degree, whereas Olszewski et al. (1978) described the lake as having the ability to create weak strata.

Oxygenation of the lake water depended on the season. Oxygen content in the autumn was similar in the whole water column and equalled 9.8 mg

$O_2 \cdot dm^{-3}$ (74.1% saturation) – Table 2. At the end of April, oxygen content in the surface water layer was high, 16.2 mg $O_2 \cdot dm^{-3}$ (173.8% saturation) with 4.8 mg $O_2 \cdot dm^{-3}$ (39.9% saturation) near the bottom (Table 2). In the peak of the summer stagnation, oxygen conditions deteriorated. High concentrations of the gas were measured only in the 4-m thick layer (from 113.5 to 84.0% saturation), decreasing in the deeper layers to reach the zero value at 7 m depth (Table 2). Good oxygen conditions from April until September must have been due to the intensive primary production as confirmed by the deficit of free carbon dioxide and the high reaction (9.02 pH in April, 8.30 pH in September) – Table 3. Simultaneously, organic matter decomposed in the near-bottom water layers due to the continuous thermal stratification, consuming all oxygen and causing its total deficit near the bottom. The intensive mineralization of organic compounds occurred in parallel to an

Table 3

Selected chemical parameters of water of Lake Giłwa

Parameter		Date		
		21 Nov.	29 Apr.	03. Sept.
Reaction (pH)	*P*	8.12	9.02	8.30
	D	8.00	8.15	7.37
Carbon dioxide (mg $CO_2 \cdot dm^{-3}$)	*P*	8.8	0.0	0.0
	D	11.0	11.0	29.0
Conductivity ($\mu S \cdot cm^{-1}$)	*P*	368	417	321
	D	370	357	476
Chlorides (mg $Cl \cdot dm^{-3}$)	*P*	15.0	16.0	16.0
	D	15.0	20.0	19.0
Calcium (mg $Ca \cdot dm^{-3}$)	*P*	54.98	57.83	49.98
	D	54.98	65.69	73.54
Magnesium (mg $Mg \cdot dm^{-3}$)	*P*	14.0	7.6	7.2
	D	14.0	10.0	21.2
Alkalinity (mval $\cdot dm^{-3}$)	*P*	3.1	3.1	2.7
	D	3.1	3.5	5.0
Total hardness (mval $\cdot dm^{-3}$)	*P*	4.00	3.57	3.14
	D	4.00	4.18	5.57
Oxidization (mg $O_2 \cdot dm^{-3}$)	*P*	11.2	12.8	28.8
	D	12.0	17.6	24.0
BOD_5 (mg $O_2 \cdot dm^{-3}$)	*P*	2.1	7.4	6.6
	D	3.2	1.9	4.7

P – surface layer
D – bottom layer

increase in free carbon dioxide (to 29.0 mg $CO_2 \cdot dm^{-3}$ in September) – Table 3. According to ROGALSKI et al. (2005), carbon dioxide is the main product of respiration and matter decomposition processes occurring in the bottom mud. The described distribution of oxygen in the peak of the summer stagnation is illustrated by the so-called clinograde curve, typical for eutrophic lakes.

One of the indicators of excessive water fertility is the low visibility of Secchi disc. Water transparency in Lake Giłwa ranged from 0.70 to 2.50 m (Figure 2) and oscillated during the vegetation period around 0.8 m. Apparently, the excessive biomass of algae was the limiting factor for sunlight penetration in the lake, as shown by the highest amount of chlorophyll *a* (indicator of the primary production, equal 73.50 $mg \cdot m^{-3}$), which occurred simultaneously with the lowest water transparency (0.70 m) – Figure 2.

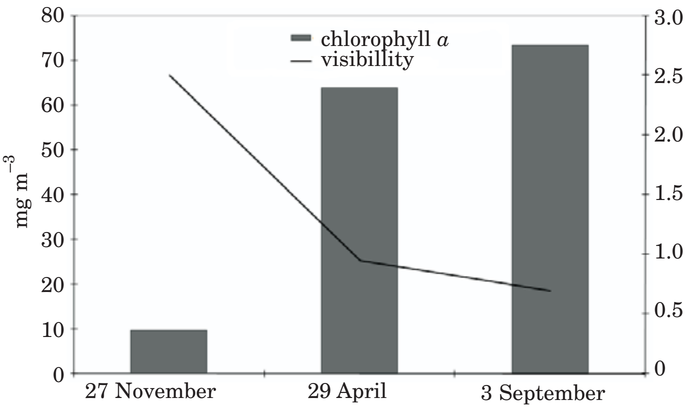

Fig. 2. Chlorophyll *a* content and visibility of Secchi disc in water of Lake Giłwa

The excessive primary production in Lake Giłwa was most probably caused by the high concentration of nutrients, which ranged from 2.30 to 12.47 mg $N \cdot dm^{-3}$ and from 0.13 to 1.40 mg $P \cdot dm^{-3}$ (Figures 3, 4). Such values are typical for highly fertile lakes. The pools of nitrogen and phosphorus were dominated by organic forms (Figures 3, 4), which confirms the high fertility and productivity of the lake (GROCHOWSKA, TANDYRAK 2007). Following the lake classification by ZDANOWSKI (1982), Lake Giłwa can be classified as polytrophic, i.e. 4^{th} trophic condition degree, in terms of the spring content of total P. According to HILLBRICHT-ILKOWSKA and WIŚNIEWSKI (1993), who included water transparency, total P and chlorophyll *a* into their classification, Giłwa is the heavily eutrophic lake.

Assessment of the production processes in a lake is possible through BOD_5 determination. In the surface waters of Lake Giłwa, the values of that parameter were high, approx. 7 mg $O_2 \cdot dm^{-3}$, during the vegetation period, demonstrating fairly advanced eutrophication. At the same time, the permanganate value (BOD_5-Mn), which reveals the reservoir's abundance in

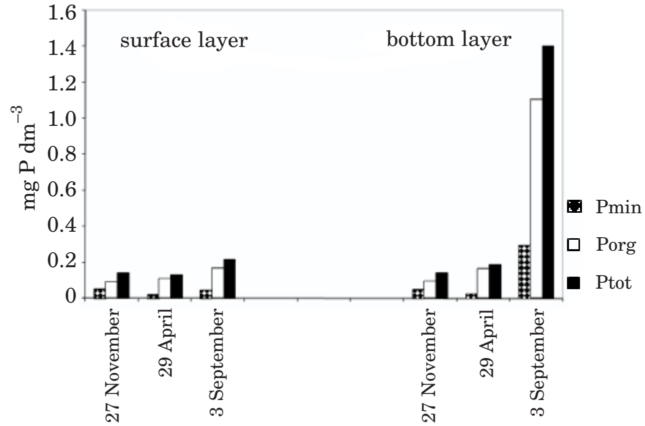

Fig. 3. Changes of phosphorus compounds content in waters of lake Giłwa

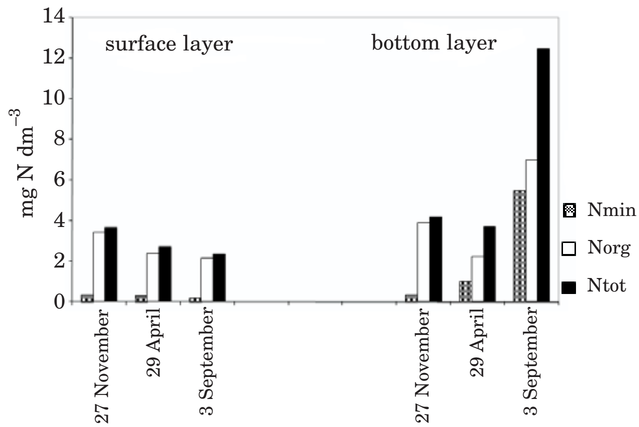

Fig. 4. Changes in the content of nitrogen compounds in water of Lake Giłwa

allochthonous organic matter, was determined in Lake Giłwa waters. The values ranged from 11.2 to 28.8 mg $O_2 \cdot dm^{-3}$ (Table 3). The ratio between the permanganate value and the BOD_5 was all the time higher than 1.0, ranging from 1.7 to 5.3. Such a ratio indicates the dominance of organic matter resistant to degradation over the easily degradable fraction, which can be attributed to the afforested surroundings of the lake and the influence of the Giłwa River, which received treated sewage. JANUSZKIEWICZ (1969) argues that afforested watersheds export to the water large amounts of humic compounds resistant to biological decomposition.

OLSZEWSKI and PASCHALSKI (1959), who examined the alkalinity of the Mazurian Lakes, distinguished three groups. The alkalinity of Lake Giłwa (2.7--5.0 mval$\cdot dm^{-3}$; Table 3) would classify this water body into the 3^{rd} alkalinity group, which means that its water is well buffered. Total hardness of the water in Lake Giłwa ranged from 3.14 to 5.57 mval·dm^{-3} (157.1-278.8 mg $CaCO_3$·dm^{-3}) – Table 3. In accordance with the classification by DOJLIDO (1995), the water in Lake Giłwa is hard. The hardness was mainly determined by the calcium content varying from 49.98 to 73.54 mg Ca·dm^{-3} (Table 3). Despite the forest cover of much of the watershed, the concentrations of calcium measured in the lake were high, which is assumingly due to the wastewater import by the Giłwa River. KOWALSKI (1997) claims that calcium content in the surface waters is determined by the processes initiated by the presence of organic pollutants imported with wastewater. In the surface water of Lake Giłwa, the least of calcium was observed during the summer stagnation, in parallel with the maximum chlorophyll a concentration and the lowest water transparency. Such a relationship must be connected to biological decalcification during intensive photosynthesis, which is when lack of free carbon dioxide causes degradation of calcium hydrocarbonate and free CO_2 is released (HĹKANSON et al. 2005). Neutral calcium carbonate thus created settles down and increases calcium content near the bottom. This explanation seems to be confirmed by the present study. The near-bottom water in Giłwa was calcium-rich (Table 3).

Electrolytic conductivity indicates the degree of water pollution with mineral compounds. MARSZELEWSKI (2005) analysed the electrolytic conductivity of lakes in North Poland and selected a group of eutrophic lakes in which the values of this parameter were from 200 to 400 µS·cm^{-1}. The conductivity of water in Lake Giłwa ranged from 321 to 476 µS·cm^{-1} (Table 3), corresponding to the range typical for the lakes of considerable fertility. MARSZELEWSKI (2005) report that in heavily eutrophicated lakes electrolytic conductivity in summer differs along the water column, with the values increasing towards the bottom. In Lake Giłwa, the conductivity increased with the depth (Table 3). The high electrolytic conductivity of the water in Lake Giłwa is probably related to the wastewater import.

Chloride ions dissolved in water originate from the ground or arrive with contaminants. According to the classification by OLSZEWSKI and PASCHALSKI (1959), water receiving no sewage contains to 15 mg Cl·dm^{-3}. Despite being located in an area lacking a sewage collection system, and receiving treated wastewater from the Giłwa River, Lake Giłwa was determined to contain 15-20 mg Cl·dm^{-3} (Table 3), which is only sightly in excess of the above threshold value.

CONCLUSIONS

1. Lake Giłwa is a 3rd static degree reservoir (PATALAS 1960).

2. The summer oxygen distribution in the water column follows a clinograde curve, which indicates high fertility of the lake.

3. Lake Giłwa is nutrient rich. The concentrations of nutrients are, for example, 1.4 mg P dm^{-3} and 12.47 mg N dm^{-3}.

4. According to the criteria given be ZDANOWSKI (1982), Lake Giłwa is polytrophic, i.e. 4th trophic state degree, whereas from the guidelines suggested by HILLBRICHT-ILKOWSKA and WIŚNIEWSKI it can be concluded that it is a heavily eutrophic lake.

5. The water in Lake Giłwa is well buffered, hard, and considerably rich in calcium.

6. In the water in Lake Giłwa allochthonous organic matter dominates (the ratio between the permanganate value and BOD_5 higher than 1).

7. The high fertility of the water in Lake Giłwa is confirmed by the electrolytic conductivity reaching 476 $\mu S \cdot cm^{-1}$.

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