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Physicochemical properties of water in the Glinianki pit lake in Kielce (SE Poland)

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Abstract

The article presents research results on the physicochemical properties of water and species composition of plants in the ecological site Glinianki, protecting a small pit lake in Kielce (SE Poland). The water level in the lake and water quality changed seasonally due to the inflow of snowmelt and water from adjacent episodic pools, which are rich in calcium, sulphates, and nitrates. Despite high precipitation sums in summer, water level decreased due to increased evaporation. The floral list of the Glinianki pit lake contains 37 species, mainly plants of the shoreline, emergent plants of reed beds, sedge beds and submerged rooted plants. Among the taxa found in the ecological site, there are species included in national and regional red lists, such as the Greater Bladderwort *Utricularia vulgaris*, the Eurasian Watermilfoil *Myriophyllum spicatum* and the Whorl-leaf Watermilfoil *Myriophyllum verticillatum*. Although located in the city, the catchment of the pit lake is not yet urbanised, and it should be protected to preserve the ecological site.

1. INTRODUCTION

Permanent, anthropogenic water basins, known as pit lakes, are formed in open pit mines, which intersect the local water table [Castendyk et al. 2015]. Kielce and adjacent areas were located in the Old Polish Industrial Region, with numerous open mines of raw rock materials, lime kilns and brickworks [Pająk, Szczepański 2013]. Industrialisation irreversibly changed the natural ecosystems; however, new habitats were created, and interesting rock formations and tectonic forms were exposed [Poros, Wesołowski 2019]. Abandoned quarries are among the most interesting geosites of the Holy Cross Mountains UNESCO Global Geopark [Geopark 2017]. Within the city limits of Kielce, there are four inanimate nature reserves, two documentary sites, one ecological site, and one natural and scenic complex that protects post-excitation areas. The ecological site Glinianki was established where clay for the „Zalzman and Osełka” brick factory was extracted [Poros, Sobczyk 2013; Król 2024]. The paper aims to present the research results on water quality and plant species composition in the small pit lake, shaped by human activity and natural processes, protected in the ecological site.

2. RESEARCH AREA

Ecological site Glinianki (N: 50°51'27", E: 20°38'31") is located in Kielce (SE Poland), in the Kadzielnia Range of

the Świętokrzyskie Mountains (Fig. 1). It was established in 1999 on the area of 1 ha, to protect a small pit lake (Journal of Laws of the Świętokrzyskie Province of 1999, No. 88, item 1239). The site is one of the most valuable aquatic ecosystems in the city, hosting numerous rare species of animals [Gwardjan et al. 2015, Przemyski et al. 2019]. South of Glinianki, a large post-mining area was formed due to the extraction of deposits of Upper Devonian limestones, which are protected in the Wietrzna inanimate nature reserve. The lake is surrounded with mine spoil heaps, covered with dry grasslands and clusters of trees and shrubs. Extraction of clay led to the formation of a small reservoir, at first in the northern part of the mine, and at least since 1992, in the present area of the lake. Two small episodic pools are East of the lake (Fig. 2).

3. METHODS

Field studies of selected physicochemical parameters of water (pH, electrolytic conductivity, temperature, concentration of dissolved oxygen) were conducted once a month during a year (June 2023 – May 2024), in one point located in the littoral zone, 2 meters from the shore. The measurements were conducted using a Hach HQ2200 multi-parameter water quality sensor with IntelliCAL™ pH PHC101, HACH LDO™ and CDC401 electrodes, calibrated with Hamilton standards (Reno, NV, USA, pH 4.01, 7.00, 9.21) and EC 15 µS/cm reference material (CPAchem,



Figure 1. Research area – localisation in the city (based on geoportal.pl) and general view (photo by Z. Śliwa)

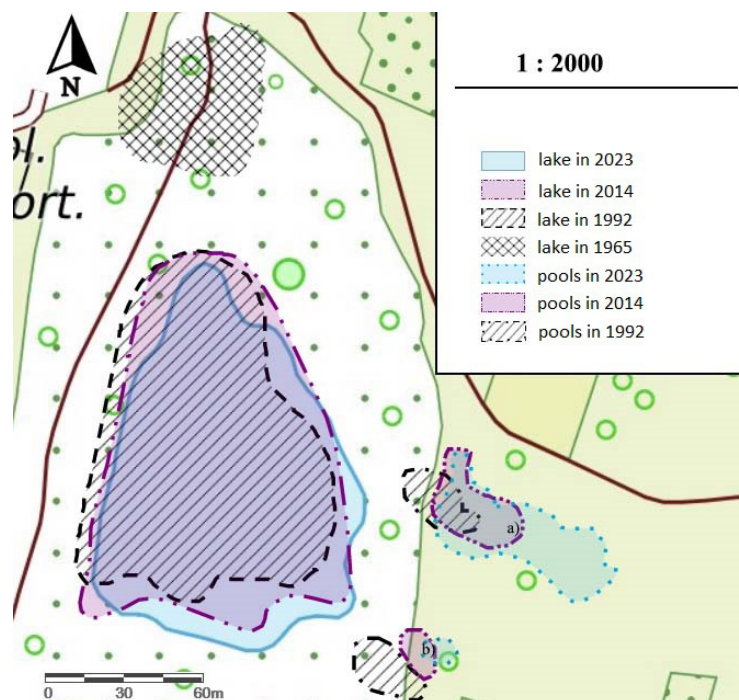


Figure 2. Water bodies in the research area; a and b – episodic pools (based on geoportal.pl)

Table 1. Morphometric parameters of the Glinianki pit lake

No.	Parameter	Unit	Value
1.	Area (A_0)	ha	1.0
2.	Length (L)	m	148.4
3.	Width (B_{sr})	m	67.6
4.	Length of the shoreline (l)	m	413.3
5.	Elongation index (λ)	-	0.01
6.	Shoreline development index (K)	-	1.2
7.	Catchment area (A)	ha	47.1
8.	Schindler's index (S)	m^{-1}	31.4

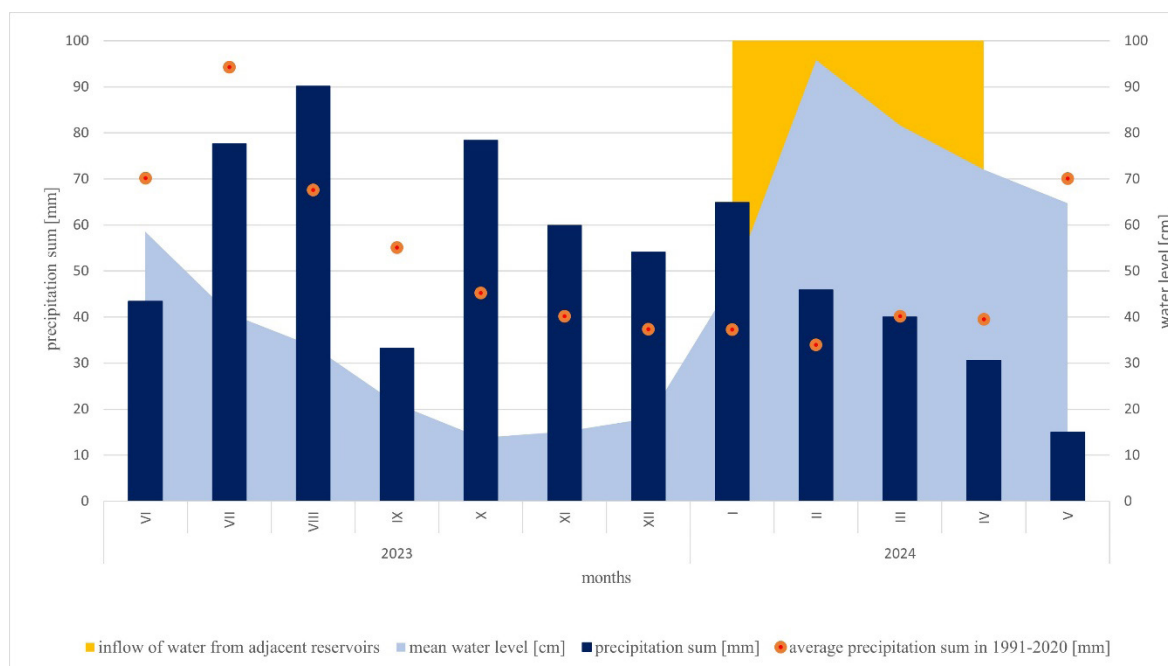


Figure 3. Dynamics of water level in the Glinianki pit lake and monthly precipitation sums (data from the IMGW-PIB meteorological station Kielce-Suków)

Bulgaria). Water samples were collected in polypropylene containers and transported to the Environmental Research Laboratory of the Jan Kochanowski University of Kielce, where the water was filtered using 2.7 μm glass microfiber filters (Whatman® GF/D). The concentration of selected ions (Cl^- , SO_4^{2-} , NO_3^- , PO_4^{3-} , Na^+ , NH_4^+ , Mg^{2+} , K^+ , Ca^{2+}) was determined with the use of DIONEX ICS 3000 ion chromatograph (Sunnyvale, CA, USA) equipped with two analytical columns: IonPac CS16 3×250 mm for cations and IonPac AS18 2×250 mm for anions. The detection level of the chromatograph was $0.4 \text{ mg} \cdot \text{dm}^{-3}$ for Ca^{2+} and $0.1 \text{ mg} \cdot \text{dm}^{-3}$ for the other ions. To control the quality of obtained results, certified reference material KEJIM-15 (Environment Canada) was used. Additionally, one of the filters was analysed using an energy dispersive spectroscope EDAX GENESIS microanalyser in the scanning electron microscope Quanta 250 FEI. Microscope analysis allowed us to determine morphological features (size and shape) and chemical composition of solid particles deposited on the filter's surface.

A staff gauge was installed and checked once a week to register changes in the pit's water level. A floral list was made in the summer of 2023 (July – September) and spring of 2024 (March-May). Registered plant species were assigned to morpho-ecological groups according to the classification proposed by Kłosowscy [2007].

4. RESULTS

Within a year, the water level in the pit lake changed seasonally by over 80 cm, with the highest level in February and the lowest in October. From January to April the lake

was alimented with water from the adjacent episodic pools (Fig. 3). Meteorological data from the IMGW-PIB station Kielce-Suków indicate that the sum of precipitation in the analysed period (June 2023 – May 2024) amounted to 628.3 mm and was close to the average total from 1991-2020 – 631.1 mm. However, the values recorded in subsequent months differed significantly from the normal conditions. The greatest deficit was noted in May 2024, when the monthly precipitation sum was only 10.5 mm, while in 1991-2020, the average amounted to 70.1 mm (15% of the normal). Other relatively dry months were June and September 2023 (62% and 60% of the average monthly totals, respectively). On the other hand, in October 2023, the amount of rainfall was 78.4 mm, which is 173% of the average precipitation in this month (45.2 mm), and higher values were noted until March 2024.

The pH value changed from pH = 7.34 (June) to pH = 8.79 (October), with the mean value of pH = 7.82. The annual mean of the electrolytic conductivity amounted to $303.7 \mu\text{S}/\text{cm}$, ranging from $173.5 \mu\text{S}/\text{cm}$ (January) to $477.0 \mu\text{S}/\text{cm}$ (April). The highest values were recorded from February to April. The mean temperature of water in the littoral zone amounted to 13.4°C , and its dynamics in the annual cycle followed the changes in air temperature. The average dissolved oxygen concentration was 8.4 mg/l, with the lowest value of 2.2 mg/l recorded in December. Due to the presence of ice cover, temperature and concentration of dissolved oxygen were not measured in January 2024 (tab. 2).

The concentrations of major ions were characterised by relatively low (Na^+ , Mg^{2+} , K^+ , Cl^-) or average (Ca^{2+} , SO_4^{2-}) variability in the annual cycle. Higher values of

Table 2. Physicochemical parameters and chemical composition of water from the Glinianki pit lake

Month	Ion concentration [mg · dm ⁻³]								pH [-]	EC [μS · cm ⁻¹]	O ₂ [mg · dm ⁻³]	Temp. [°C]
	Na ⁺	NH ₄ ⁺	Mg ²⁺	K ⁺	Ca ²⁺	Cl ⁻	SO ₄ ²⁻	NO ₃ ⁻				
VI	5.6	0.4	5.5	1.3	43.1	6.0	30.6	<0.1	7,34	289.0	10.6	20.0
VII	5.6	0.2	5.5	1.3	42.3	6.2	28.5	<0.1	8,12	229.0	6.7	21.6
VIII	5.8	0.2	5.0	1.9	38.8	6.8	21.5	<0.1	8,11	228.0	6.6	20.3
IX	6.1	0.1	4.8	2.0	44.6	7.2	19.1	<0.1	8,07	255.2	4.5	19.4
X	5.6	0.3	4.7	1.9	41.6	6.6	16.5	0.2	8,79	270.0	13.3	16.8
XI	5.5	0.2	4.1	2.4	42.1	6.8	15.5	0.3	7,74	279.0	10.2	7.5
XII	6.9	0.3	4.6	3.0	54.5	8.9	15.6	0.8	7,53	288.0	2.2	0.0
I	5.1	0.7	3.4	2.5	26.9	7.3	17.9	0.2	7,89	173.5	-	-
II	4.7	0.8	3.6	1.9	63.9	6.2	25.2	10.9	7,75	367.0	10.9	7.0
III	5.4	0.5	5.2	1.8	88.4	6.5	34.7	0.7	8,17	444.0	10.0	8.0
IV	5.3	0.4	6.0	1.8	67.4	6.4	35.7	0.4	7,91	477.0	8.5	8.9
V	6.4	0.5	7.8	2.0	66.5	6.8	41.4	5.8	8,05	345.9	9.3	17.8
Mean	5.7	0.4	5.0	2.0	51.7	6.8	25.2	1.6	7,82	303.7	8.4	13.4
Min.	4.7	0.1	3.4	1.3	26.9	6.0	15.5	<0.1	7.34	173.5	2.2	0.0
Max.	6.9	0.8	7.8	3.0	88.4	8.9	41.4	10.9	8.79	477.0	13.3	21.6
CV [%]	10	55	23	24	33	11	35	202	5	30	54	38

EC – electrolytic conductivity, O₂ – dissolved oxygen, Temp. – temperature, CV – coefficient of variation, (-) – no data

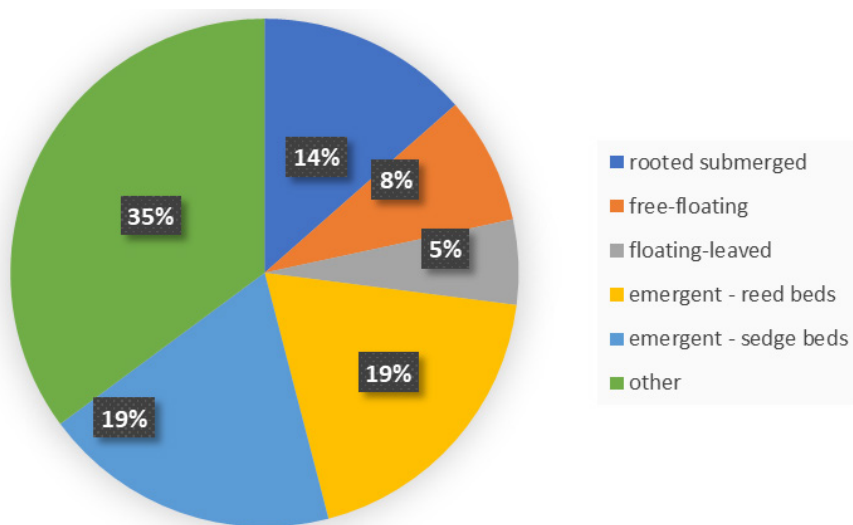


Figure 4. Plant species share morpho-ecological groups at the Glinianki pit lake

the coefficient of variation were noted in the case of ammonium (NH₄⁺) and nitrate (NO₃⁻); however, the ammonium concentrations did not exceed 1 mg/l. In 11 of 12 water samples, the phosphate concentration was lower than the detection limit. Therefore, it was not included in further analyses.

In all the analysed samples, the dominating cation was calcium (mean concentration: 51.7 mg/l), and the dominating anion – sulphate (25.2 mg/l). The

concentrations of both ions reached the highest values from February to May, in accordance with the highest values of the electrolytic conductivity. The concentration of nitrates throughout the year was low (<1 mg/l), with higher values recorded only in February (10.9 mg/l) and May (5.8 mg/l).

The floral list of the Glinianki pit lake contains 37 species (tab. 3). The most numerous groups were composed of the plants of the shoreline (35%), emergent plants

Table 3. Plant species recorded in the Glinianki pit lake

No.	Scientific name	Common name	Morpho-ecological group
1	<i>Acorus calamus</i> L.	Sweet flag	Emergent – reed bed
2	<i>Alisma plantago-aquatica</i> L.	European water-plantain	Emergent – reed bed
3	<i>Caltha palustris</i> L.	Marsh-marigold	Other
4	<i>Carex acutiformis</i> Ehrh.	Lesser pond-sedge	Emergent – sedge bed
5	<i>Carex brizoides</i> L.	Quaking sedge	Other
6	<i>Carex caryophyllea</i> Latourr.	Vernal sedge	Other
7	<i>Carex hirta</i> L.	Hairy sedge	Other
8	<i>Carex ovalis</i> Gooden.	Oval sedge	Other
9	<i>Carex rostrata</i> Stokes	Beaked sedge	Emergent – sedge bed
10	<i>Carex vulpina</i> L.	True fox-sedge	Emergent – sedge bed
11	<i>Ceratophyllum demersum</i> L. s. str.	Rigid hornwort	Rooted submerged
12	<i>Cladium mariscus</i> L.	Swamp sawgrass	Emergent – sedge bed
13	<i>Fontinalis antipyretica</i> Hedw.	Greater water-moss	Rooted submerged
14	<i>Geranium robertianum</i> L.	Herb-Robert	Other
15	<i>Glyceria maxima</i> (Hartm.) Holmb.	Great manna grass	Emergent – reed bed
16	<i>Hydrocharis morsus-ranae</i> L.	European frog-bit	Free-floating
17	<i>Iris pseudacorus</i> L.	Yellow flag	Emergent – sedge bed
18	<i>Juncus articulatus</i> L. emend. K. Richt.	Jointleaf rush	Emergent – sedge bed
19	<i>Juncus bufonius</i> L.	Toad rush	Other
20	<i>Juncus effusus</i> L.	Common rush	Other
21	<i>Juncus inflexus</i> L.	Hard rush	Other
22	<i>Juncus tenuis</i> Willd.	Slender rush	Other
23	<i>Lemna minor</i> L.	Common duckweed	Free-floating
24	<i>Lysimachia nummularia</i> L.	Moneywort	Other
25	<i>Myriophyllum spicatum</i> L.	Eurasian watermilfoil	Rooted submerged
26	<i>Myriophyllum verticillatum</i> L.	Whorl-leaf watermilfoil	Rooted submerged
27	<i>Nymphaea alba</i> L.	White waterlily	Floating-leaved
28	<i>Phalaris arundinacea</i> L.	Reed canary grass	Emergent – sedge bed
29	<i>Phragmites australis</i> (Cav.) Trin. ex Steud.	Common reed	Emergent – reed bed
30	<i>Polygonum amphibium</i> L.	Longroot smartweed	Floating-leaved
31	<i>Polygonum bistorta</i> L.	Common bistort	Other
32	<i>Polygonum hydropiper</i> L.	Marshpepper knotweed	Other
33	<i>Potamogeton lucens</i> L.	Shining pondweed	Rooted submerged
34	<i>Schoenoplectus lacustris</i> (L.) Palla	Lakeshore bulrush	Emergent – reed bed
35	<i>Typha angustifolia</i> L.	Lesser bulrush	Emergent – reed bed
36	<i>Typha latifolia</i> L.	Common bulrush	Emergent – reed bed
37	<i>Utricularia vulgaris</i> L.	Greater bladderwort	Free-floating

of reed beds (19%), sedge beds (19%) and submerged rooted plants (14%; Fig. 4). Among the taxa found in the ecological site, the Greater Bladderwort *Utricularia vulgaris* L. is assessed in the national red list of plants as a species near threatened [Każmierczakowa et al. 2016], while the Eurasian Watermilfoil *Myriophyllum spicatum* L. and the Whorl-leaf Watermilfoil *Myriophyllum verticillatum* L. are included in the regional red list of the Małopolska Upland [Bróz, Przemyński 2009].

The microphotograph of the filter surface showed the presence of characteristic particles (Fig. 5). Its EDS analysis indicated that they were composed mainly of Ca, O, Au,

C, Mg, Al and Si (the presence of gold was connected to the process of sample preparation). According to atomic weight (Wt%) the structures were composed mainly of calcium (41%), oxygen (30%) and carbon (8%).

5. DISCUSSION

Depending on water's physical and chemical parameters, pit lakes can threaten the environment or become valuable habitats for aquatic ecosystems [Molenda et al. 2020; Lund, Blanchette 2023]. As the water in a pit lake comes from groundwater (seeping through the pit walls

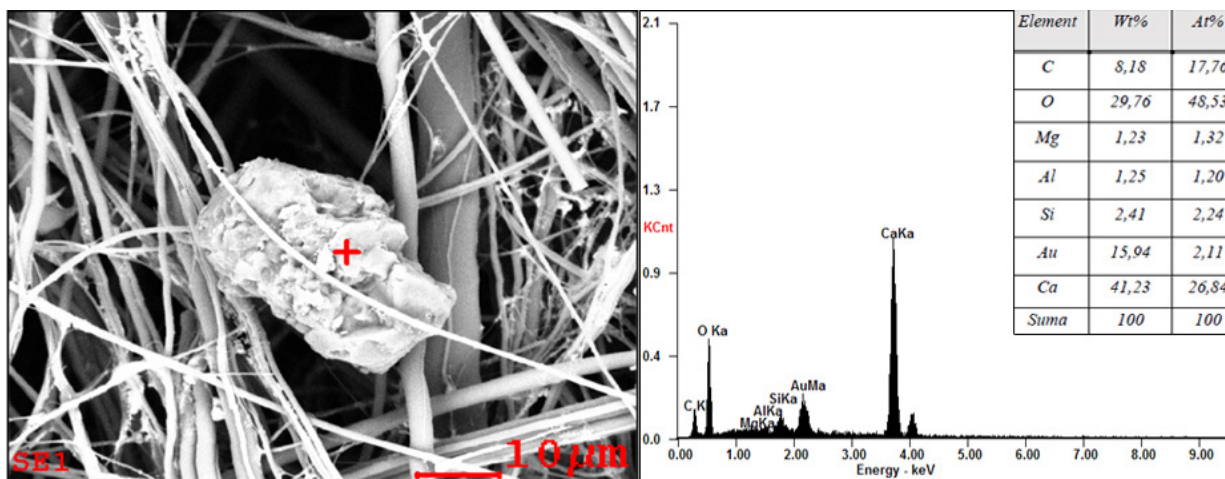


Figure 5. Microphotograph of a particle on the surface of a glass filter and its chemical composition

and floor), rainwater and snowmelt (washing over the pit walls), water quality is affected mainly by the geological setting [Blowes et al. 2003; Castendyk et al. 2015]. Pits created by mining chemically inert materials, such as sand, gravel, clay, bentonite and limestone, tend to mirror the geo-chemistry of their surroundings [Soni et al. 2014]. The chemical composition of water in reservoirs formed on limestone depends on the infiltration of rain and snowmelt from surrounding areas; however, it can also be affected by the inflow of water through a complicated network of karstic cavities, as is the case in the Zakrzówek quarry in Kraków [Motyka et al. 2022]. Research conducted in Zakrzówek showed a hydraulic connection with the nearby Vistula River and proved the need for long-term monitoring of water chemistry dynamics in karst areas. Water from the Glinianki pit lake had lower values of pH and electrolytic conductivity, as well as lower concentrations of phosphorus and nitrogen, than water from clay pits in Poznań, where the community of aquatic plants was much poorer [Kuczyńska-Kippen et al. 2006]. However, data from pit lakes formed in the sites of clay excavation are scarce, as the researchers focus mainly on acidic lakes in coal and quartzite mines, which harm the surrounding ecosystems [e.g. McCullough, Van Etten 2011; Molenda et al. 2020; Paulsson, Widerlund 2021]. SEM analysis showed no specific contaminants in the water from the pit lake. Particles present on the filter were composed mainly of calcium, carbon and oxygen. Their chemical composition and characteristic structure indicate calcite rhombohedrons, which freshwater algae can form [Messyasz et al. 2014].

High value of the Schindler's index, calculated for the Glinianki pit lake (31.4 m⁻¹), indicates the reservoir's dependence on its catchment area [Bajkiewicz-Grabowska, Mikulski 1999]. Due to global climate change, involving higher temperatures, reduced ice and snow cover and altered precipitation patterns, small lakes are particularly vulnerable ecosystems [Woolway et al. 2020]. Our research shows that despite the high precipitation sums in summer

(July and August), the water level in the Glinianki pit lake declined, which can be attributed to high air temperatures and increased evaporation. The highest level was recorded from January till April when the lake was alimeted from snowmelt, surface flow and inflow of water from adjacent episodic pools. The water inflow resulted in elevated electrolytic conductivity, which was connected mainly to higher concentrations of calcium, sulphates and nitrates. The increased concentrations of the three ions can be linked with natural sources [Zak et al. 2021], such as the weathering of local rocks and the decomposition of organic matter in the lake and the episodic pools. Increased concentration of nitrates in February could be caused by the inflow of polluted snowmelt and water from episodic pools, while in May, with extremely low rainfall and decreasing water level in the pit, it could be attributed to weathering of bedrock nitrogen [Holloway, Dahlgren 2002]. The snowmelt did not result in elevated concentrations of sodium and chlorides, which is characteristic of urban water bodies, due to winter maintenance of roads and pavements [Fournier et al. 2020]. The catchment area of the Glinianki pit lake has not been urbanised, yet there are plans to introduce new roads, housing estates and sport and recreation services in the close vicinity of the lake [MPZP 2011], which can potentially harm water quality. Results of our studies show that in terms of the analysed parameters of water quality and species composition of plants, the Glinianki ecological site hosts a valuable aquatic ecosystem, deserving conservation and special attention from the city's authorities, e.g. in the process of spatial planning.

6. CONCLUSIONS

Despite its anthropogenic origin, the studied water body is an interesting and valuable element of the natural environment in the city. Taking into consideration the impact of the catchment area on water quality and the implications of global climate change, to preserve the

lake's ecosystem, the whole catchment should be taken under protection, including the episodic pools, which are now outside of the ecological site. Further research on the changes in groundwater level, water level in the pit, meteorological conditions and the response of the plant community is needed to obtain complete knowledge of the functioning of this lake's ecosystem.

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