Limnological Study on a Lake Formed in a Limestone Quarry (Kraków, Poland). I. Water Chemistry

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Abstract

Chemical investigation of water from a 21 ha lake with a maximum depth of 32 m formed in a former limestone quarry south of Kraków, Poland was carried out. The lake is meromictic, with maximum values of O_2 in mixolimnion, and water homothermy noted in December. The important influence of the polluted Vistula River, flowing only in 600m distance that mainly infiltrates the quarry, resulted in high chloride content and conductivity value. Low chlorophyll a concentration and TSI_{SD} value show that the lake is oligotrophic, whereas the nutrient concentrations indicate slightly higher trophy.

Keywords: quarry lake, meromictic, water chemistry, trophic state

Introduction

Post-exploitation water reservoirs may play a role as climatic, natural, recreational or holiday factors and in water retention. Their role is important in the structure and functioning of the landscape [1]. Quarry lakes form a class of post-exploitation water reservoirs, whose role in transformed landscapes constantly increases. Water chemistry of the quarry lakes varies and depends mainly on the lithology of the catchment area (types of excavation) and sources of water inflowing to them (precipitation, underground infiltration and others). There were no hydrobiological studies on the Zakrzówek lake formed in 1991. Only the chemical composition of numerous effluents in the quarry were investigated [2, 3].

In the years 2000-2001 the chemical composition of Zakrzówek lake water was investigated and this paper presents the first results of that investigation.

Study Area and Methods

Zakrzówek Lake is located in the southern part of Kraków (50° 02' 10"N, 19° 54' 40"E, 213 m a.s.l), in the area of a small horst structure known as the "Skałki Twardowskiego". The structure is comprised of Upper Jurassic limestone, which had been mined until 1991 for the needs of the soda works as well as marls for cement production. The deepest exploitation level reached a depth of about 60 m below the surface, which is about 30 m below the water level of the Vistula River flowing 600 m west from the quarry. The Vistula River was the main source of water in Zakrzówek [3]. The process of filling in the former quarry ended in 1997. Now, the lake area is 21 ha (Fig.1) with a maximum depth of 32 m. Due to the quarrying method, the borders of the quarry are almost vertical and rise up to 20 m above the water level. The

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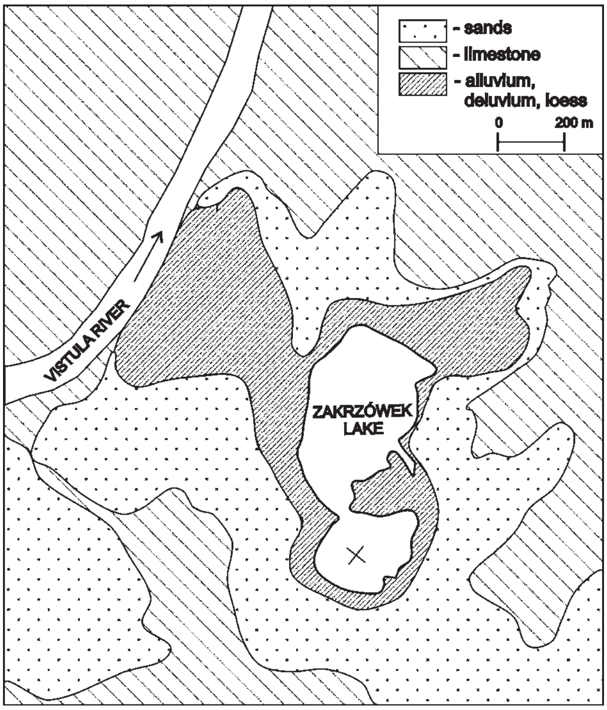

Fig. 1. Map of Zakrzówek lake, x – sampling point.

lake has been artificially stocked with fish, which have not yet been studied.

Water samples were taken monthly from April 2000 to March 2001 (except for February when the lake was partially frozen) from 0, 2.5, 5, 7.5, 10, 12.5, 15, 18.5 and 20 m; below 20 m H_2S was detected. A parallel study of the zooplankton community [4] was also limited to the same depth, since deeper layers remained constantly anoxic. Lake water for total chlorophyll *a* estimates was taken from depths of 0, 5, and 10 m, and pooled into an integrated sample. Chemical analyses of water and total chlorophyll *a* were performed according to Standard Methods [5]. Depth of Secchi's disc (SD) was used to calculate the Carlson Trophic State Index (TSI_{SD}) [6]. Results concerning monthly changes of the main ion concentration and conductivity values during the year were given as yearly means.

Results

Temperature stratification occurred throughout most of the year, while homothermy was noted in late December (Fig. 2 A). From the surface to the depth of 18 m (mixolimnion) the O_2 concentration ranged from 9 to 12 mg O_2 L^{-1}, while below 18 m (monimolimnion) it dropped rapidly (Fig. 2B), and H_2S was detected.

The highest oxygen saturation in Zakrzówek was observed from March to October at a depth of 5-15 m, while the lowest one was found in monimolimnion (Fig. 2 C). At the lake surface CO_2 concentration was 1 mg L^{-1}, and increased from 7 to 35 mg L^{-1} in monimolimnion (Fig. 2 D). In December, when homothermy was observed, water

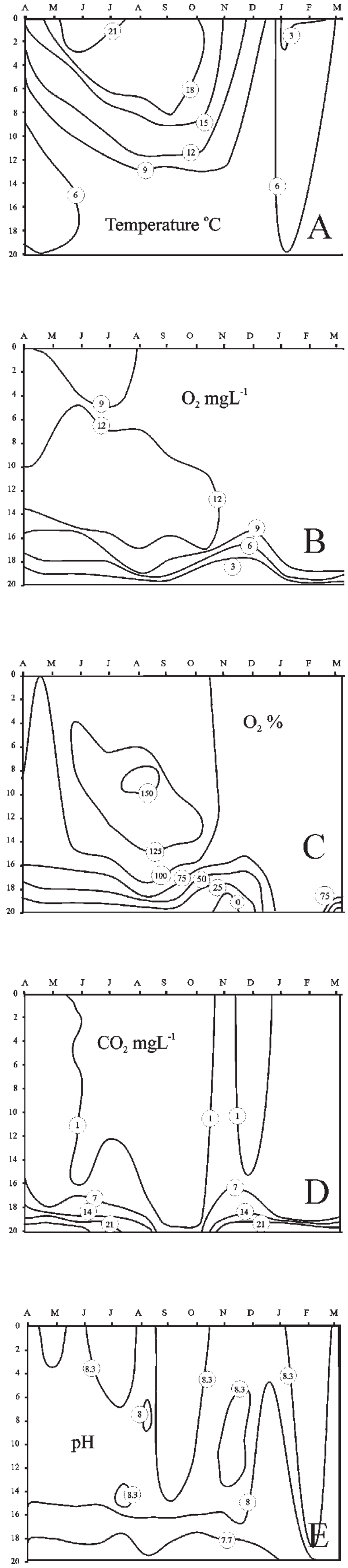

Fig. 2. Isopleth of temperature (A), oxygen concentration (B), oxygen saturation (C), CO_2 concentration (D), pH value (E) in the Zakrzówek lake.

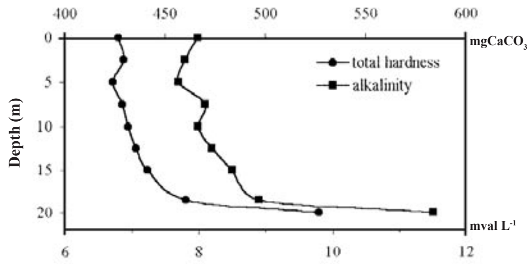

Fig. 3. Mean value of alkalinity (black square) and total hardness (black circle) in the Zakrzówek lake.

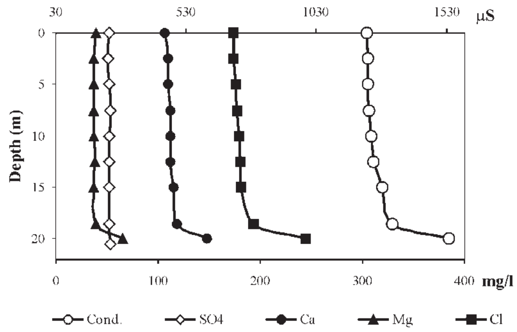

Fig. 4. Mean Ca, Mg, Cl, SO_4 concentrations and conductivity value in the Zakrzówek lake.

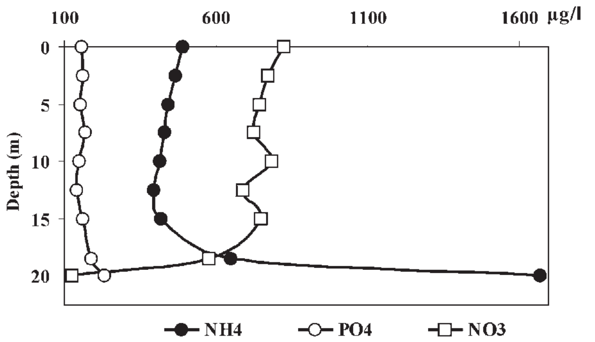

Fig. 5. Mean NH_4, NO_3 and PO_4 concentrations in the Zakrzówek lake.

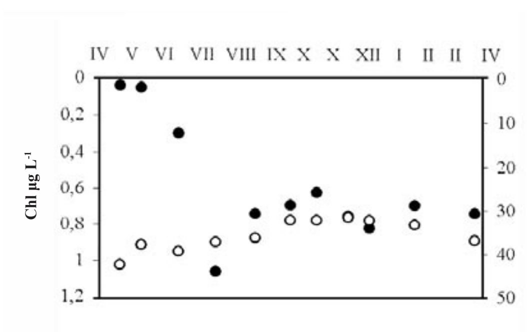

Fig.6. Seasonal changes in chlorophyll *a* (black circle) concentration and TSI_{SD} value (white circle).

did not mix completely - CO_2 and O_2 concentrations were not identical from the lake surface to a depth of 20 m. The value of pH decreased slightly throughout the whole vertical profile from 8.3 at the water surface to the value of 8 at 15 m and 7.7 at 20 m (Fig. 2 E).

Values of mean water alkalinity and total hardness increased from the surface level to 20 m: from 8 to 11.5 mval L^{-1} and from 427 to 527 mg $CaCO_3$ L^{-1}, respectively (Fig. 3). The lake water showed high conductivity, calcium, magnesium and chloride concentrations with very high values at a depth of 18.5-20 m (Fig. 4), where the chemocline formed. The average value of sulphates was 237 mg L^{-1}; which did not vary distinctly in the water column and during the year (Fig. 4). The annual mean concentration of phosphates was 167 µg L^{-1}, and also did not change significantly with depth (Fig. 5). The maximum value of PO_4 was found in May (270 µg L^{-1}); in other months it ranged between 100 and 190 µg L^{-1}. Nitrate concentration decreased markedly from the lake surface to the depth of 20 m from 824 to 122 µg L^{-1}, while ammonium content increased markedly from 154 to 232 µg L^{-1}, respectively (Fig. 5).

Chlorophyll *a* content ranged from 0.049 µg L^{-1} in April to 1.06 µg L^{-1} in July, while the Secchi disk depth fluctuated from 5.6 m in April to 17 m in November (Fig. 5). TSI_{SD} values ranged from 32 to 43 during the studied year with the mean value of 36.

Discussion

The Zakrzówek lake, a former limestone quarry, is a meromictic water body. Homothermy was observed in December but oxygen and CO_2 concentration analyses up to the depth of 20 m in the lake indicated that winter mixing did not comprise all the water mass, leaving the deepest part of the lake not disturbed. Incomplete circulation results in the formation of mixolimnion (18.5-20 m), monimolimnion below 20 m and chemocline in between. The same stratification was observed in the meromictic Lake El Tobar located in a karstic formation [7] and lake Cadagno [8]. The occurrence of hydrogen sulphide in the deepest part of the studied lake resulted from marked oxygen depletion in the deep water, and was observed in another deep lake formed in a former granodiorite quarry [9]. Among man-made lakes created in former quarries, meromictic lakes are observed very often [9, 10, 11].

The lake water had high chloride content and conductivity values as a result of the substantial influence of the Vistula River. Its water average values of 1097 mg L^{-1} while in water inflows in the former quarry Cl^{-1} concentration ranged between 90 and 1099 mg L^{-1} [2]. In this study chloride concentration ranged between 71 and 274 mg L^{-1}, whereas in the Vistula of 738 mg $L^{-1}$was observed [12]. The quarry has been filling up with Vistula water until 1997, and since then the process of freshwatering of Zakrzówek has been observed: the water mixed with precipitation and underground waters, which infiltrate the catchment area. A 58% decline in chloride concentration when compared with the value from 1996 (Motyka personal communication) confirms this process.

The high sulphate concentration (average 236 mg L^{-1}) in Zakrzówek may be a consequence of the lithology of the catchment area. It may originate from leaching of soils and miocene sediments, also from the oxidation of iron sulphides disseminated within the limestone facilitated by the extension of the range of aeration zone due to constant dewatering when the quarry operated [3]. The lack of increased concentration of sulphates at the chemocline may be due to their reduction by sulphate-reducing bacteria under anoxic conditions [8]. These conditions are also responsible for the rise in ammonium value and the decline in nitrate concentration at that depth.

According to OESD criteria [13] the lake can be classified as oligotrophic, taking into regard mean chlorophyll *a* concentration. The amount of chlorophyll *a* found in oligotrophic Slovenian high mountain lakes situated on the calcareous substratum was low (0.03-1.0 µg L^{-1}) [14] and comparable to that found in Zakrzówek lake. High water transparency and range of TSI_{SD} values from 32 to 42 also support the oligotrophic state of the studied lake. However, Secchi`s disc visibility in water depends not only on chlorophill *a* concentrations, but also on abiotic factors such as the content of mineral suspension periodically noted in Zakrzówek.

The phytoplankton community was poor in Zakrzówek [4], although the quantity of available biogens needed for its development seems to be sufficient. The annual average concentrations of phosphates (170 µg L^{-1}), nitrate (670 µg L^{-1}) and ammonium (590 µg L^{-1}) were much higher than these found in Slovenian lakes from the Julian Alps situated on a similar geological substratum [14], but much less than those noted in eutrophic lakes [15].

Meromictic lakes are an excellent model system for many limnological studies [14, 15]. A close relationship between water chemistry and biology indicates the need for further hydrobiological research and monitoring of Zakrzówek lake.

Conclusions

1. Lake Zakrzówek is a 31 m deep post-exploration meromictic lake with oxic mixolimnion, a chemocline between 18.5 and 20 m, and anoxic monimolimnion below 20 m.
2. High concentrations of calcium and sulphates in the water is the effect of its geological structure while high chloride content was the effect of the polluted Vistula River, whose water mostly filled the quarry.
3. The process of water salinization during the rime of filling up the quarry stopped in 1997 and the opposite freshwatering process has started.
4. Low chlorophill *a* concentration and TSI_{SD} value show that the lake is oligotrophic, whereas the nutrient concentrations indicate slightly higher trophy.

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