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WATER QUALITY IN RECREATIONAL RESERVOIRS IN THE CRACOW AREA

JAKOŚĆ WODY W ZBIORNIKACH REKREACYJNYCH NA TERENIE MIASTA KRAKOWA

A b s t r a c t

This paper presents a water quality assessment for the eight recreational water reservoirs located in the Cracow area. This assessment was performed on the basis of water samples collected during three seasons in 2013. The results showed that in the majority of these reservoirs, water had a good level of quality (class II), and was also suitable for recreational purposes (bathing) and as a fish habitat. In reservoirs where water quality parameters were below threshold levels (unclassifiable), such conditions resulted primarily from the location being in the vicinity of pollution surface run-off sources.

Keywords: *water reservoirs*, *Cracow area*, *water quality*

S t r e s z c z e n i e

Artykuł prezentuje ocenę jakości wód w ośmiu rekreacyjnych zbiornikach wodnych na terenie Krakowa. Ocenę przeprowadzono na podstawie próbek wody pobranych w 3 sezonach w roku 2013. Wyniki wykazały, że w większości zbiorników woda ma dobrą jakość (II klasa) i nadaje się również do celów rekreacyjnych i bytowania ryb. W zbiornikach, w których wyniki wskazywały na jakość pozaklasową, stan ten był efektem przede wszystkim niekorzystnej lokalizacji zbiornika w pobliżu powierzchniowych źródeł zrzutu zanieczyszczeń.

Słowa kluczowe: *zbiorniki wodne*, *Kraków*, *jakości wód*

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1. Introduction

Cracow (population 850,000) is located in the Silesian-Cracow industrial region in southern Poland. The territory of the Cracow area is of approximately 327 square km. The city is located on the border of a few different physiographic regions such as the Cracow Upland, the Carpathian Foothills, and the Sandomierz Basin. The Vistula is the main river here, flowing from west to east for over 41.2 km.

There are many water reservoirs in the area of Cracow. Most of these are of an artificial origin, located in exploited and abandoned quarries and open pits [5]. Despite strong industrial influence it was observed that some reservoirs kept their natural values and became attractive recreational places in Cracow [4].

The aim of this paper is to assess water quality in a physico-chemical context, and impact of catchment localization and function. This assessment also allowed discussions on water quality in the context of bathing quality and the impact on the habitat for fish.

2. Study area

According to Ciszewski at al. [1] there are seven types of reservoirs in the Cracow area: reservoirs located in open pits (after exploitation of sands, gravels, limestones); fish lakes; reservoirs located in former channels (from the present, early 20th century, and pre-industrial periods); recreational reservoirs; drinking water reservoirs; industrial lakes; reservoirs that don't fit any of the other classifications.

Reservoirs located in open pits are the most numerous, and some of these are used for recreation (Table 1). There are also a lot of reservoirs located in the former channels of the

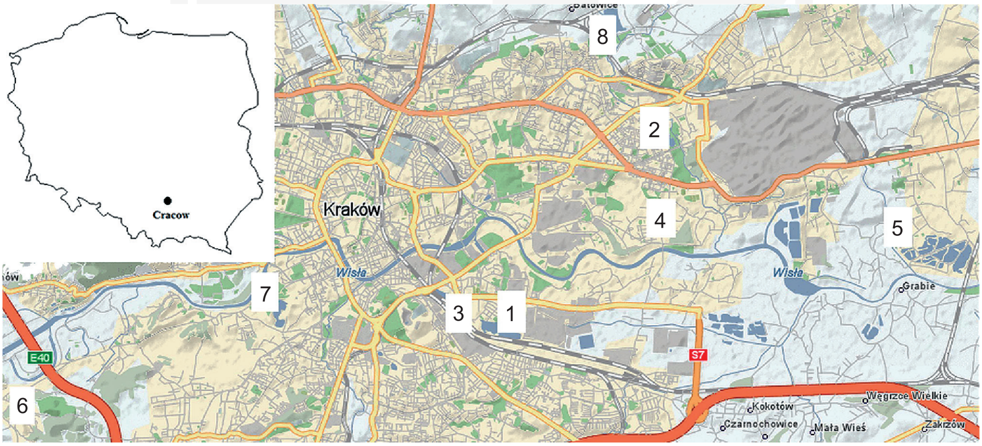

Fig. 1. Localisation of water reservoirs in the Cracow area [7]: 1. Bagry Reservoir, 2. Nowohucki Reservoir, 3. Płaszowski Reservoir, 4. Dąbski Reservoir, 5. Przylasek Rusiecki Reservoir, 6. Tyniec Reservoir, 7. Zakrzówek Reservoir, 8. Zesławice Reservoir

Vistula River. These were created during engineering works related to the organisation of navigation channels in recent times and in the beginning of the 20th century. Some of these were also formed naturally during preindustrial times [6].

Table 1

Characteristics of the water reservoirs in the Cracow area

Reservoirs	Surface area	Main use
Bagry	29 ha	swimming area, two marinas, boat hire, protected area due to the existing environmental resources [11]
Nowohucki	17 ha	located in a green protected zone, the largest recreational reservoir in the old part of the Nowa Huta district [2]
Płaszowski	15 ha	used as a fish lake and recreational reservoir [10]
Dąbski	3 ha	habitat for rare species of plants and animals [8]
P.Rusiecki	87 ha	used as a fish lake and recreational reservoir [4]
Tyniec	16 ha	created on the right bank of the Vistula River, used for fishing [12]
Zakrzówek	12 ha	diving center, alleys, bike trails, protection of the local biodiversity a Special Protection Area (SPA) within the Nature 2000 network [4]
Zesławice	24 ha	breeding ground for many water birds and fish species, used for fishing [3]

3. Materials and methods

3.1. Sampling and preparation of water samples

Sampling was performed in 2013 and water samples were collected from all eight reservoirs located within the Cracow city borders. Sampling sites were selected due to the best water access. Each sample was placed in a previously washed plastic bottle. Sampling was performed three times: in summer, autumn, and winter. However, due to the severe ice conditions, the winter sample from the Bagry Reservoir is missing. The water analysis was carried out within 24 hours of sampling, and samples were kept at a temperature of 4°C prior to analysis. Samples were filtered using blotting filter papers due to the presence of sediments, algae and other micro-organisms. The permeability of the blotting filter papers used in the study was equivalent to 0.45 um standard filters.

3.2. Water analyses

Water quality parameters were determined using standard methods. The electro--conductivity of the water samples was measured with the conductometer (inoLab ® WTW Cond 7110) and water reaction by the CP-401 pH-meter (Elmetron Company). To determine the concentrations of NH_4^+ and PO_4^- powder and cuvette tests (with a special coded scale) were used (Merck). These concentrations were measured using a spectrophotometer (Spectroquant ® NOVA 60 with a 50 mm). Concentrations of NO_2^- and NO_3^- were also measured with a spectrophotometer (Spectroquant ® Pharo 300 with a 10 mm cuvette). The measurements were performed at a wavelength of 540 nm (NO_2^-) and 410 nm (NO_3^-). The total water hardness was determined by the complexometric method, chlorides by the Mohr`s titration method and COD (chemical oxygen demand) by the potassium permanganate acidic titration method.

4. Results

Results of the water analyses are listed in Table 2 – this shows the mean of total water quality parameters for all the reservoirs.

Table 2

Mean average values of water quality parameters

Reservoirs	pH	Total hardness [mgCaCO$_3$/dm^3]	Conductivity [µS/cm]	COD [mgO$_2$/dm^3]	Chlorides [mgCl/dm^3]	Ammonium [mg/dm^3]	Nitrites [mg/dm^3]	Nitrates [mg/dm^3]	Phosphates [mg/dm^3]
Bagry	6.89	373	1047	8.03	154.3	0.423	0.024	0.950	0.19
Nowohucki	7.23	293	548	7.34	27.1	0.196	0.078	4.831	0.35
Płaszowski	7.55	360	1004	8.18	128.5	0.294	0.022	0.540	0.35
Dąbski	7.55	575	1354	10.5	131.6	0.306	0.008	2.718	0.99
P.Rusiecki	7.37	323	688	7.81	52.5	0.292	0.081	0.782	0.22
Tyniec	7.10	340	1653	11.7	419.5	0.477	0.096	2.578	0.41
Zakrzówek	7.36	442	1143	4.34	147.9	0.075	0.020	3.491	0.14
Zesławice	7.46	318	604	3.63	20.7	0.219	0.101	13.35	0.63

Water pH values showed relative stability and varied between 6.89 and 7.55. The total hardness of the investigated samples was rather low, and varied from 293 up to 575 mg/dm^3 $CaCO_3$. On the other hand, conductivity showed considerable variability, ranging from 548 µS/cm in the Nowohucki Reservoir up to 1653 µS/cm in the Tyniec Reservoir. The calculated standard deviations were in the range of 9.27 for the Zesławice Reservoir up to 293.5 for the Bagry Reservoir. High standard deviation values indicate large conductivity fluctuations.

The average values of COD for each reservoir were in the range of 3.63 up to 11.67 mgO_2/dm^3. The water in the Tyniec Reservoir reached the highest COD, while the lowest occurred in water in the Zesławice Reservoir. The calculated standard deviations were in the range of 0.82 for the Zesławice Reservoir up to 2.37 for the Dąbski Reservoir. High standard deviation values indicate large COD fluctuations.

Chlorides also showed high variability, with values between 20.7 and 419.5 $mgCl/dm^3$. The highest concentration was found in the Tyniec Reservoir (419.5 $mgCl/dm^3$). Chloride concentrations also exceeded 100 $mgCl/dm^3$ in the Bagry, Płaszowski, Dąbski and Zakrzówek Reservoirs.

Concentrations of NH_4^+ were low, and varied between 0.075–0.477 mg/dm^3. The presence of NO_2^- in water indicates that oxidation or reduction processes occurred. Only in the Przylasek Rusiecki reservoir (0.081mg/dm^3), the Zesławice Reservoir (0.101 mg/dm^3), the Nowohucki Reservoir (0.078 mg/dm^3) and the Tyniec Reservoir (0.096 mg/dm^3) were the concentrations high. The concentration of NO_3^- in surface waters was usually at low concentrations and varied from 0.540 mg/dm^3 (in the Płaszowski Reservoir) up to 13.35 mg/dm^3, whereas in the Zesławice Reservoir, it was significantly higher.

The average values of phosphates for each reservoir were in the range of 0.14 to 0.99 mg/dm^3. A slightly greater concentration was detected in the Dąbski Reservoir whereas concentration in the Zakrzówek Reservoir did not exceed the phosphate limit value (0.14 mg/dm^3). The calculated standard deviations ranged from 0.005 for the Bagry Reservoir to 0.67 for the Płaszowski Reservoir. A high value of standard deviation indicates a large degree of phosphate fluctuation between all the seasons.

5. Discussion

The overall water quality assessment, based on the data sequences from 2013, revealed that the range of the contaminants in the reservoirs indicates the effects of both the localisation and their function.

According to the current Polish legislation on water quality, Regulation of the Ministry of Environment of 9th November 2011 (classification of surface water bodies and environmental quality standards for priority substances), water quality in the Cracow reservoirs is assessed on a two-degree scale (Table 3). This scale presents numerical standards for the physico-chemical parameters only for high and good classes (I and II). For the values which did not meet the standards, the term ‘unclassifiable’ is used in the discussion. For this group, the quality class according to the former five-degree classification (Regulation of the Ministry of Environment of 11th February 2004) was added in parenthesis (Table 3).

If one or more indicators of the water quality exceeds the limit value, then the overall assessment of water quality is affected by the worst of these parameters. Classification performed on the reservoir dataset showed that water in the Bagry, Nowohucki, Rusiecki and Zakrzówek Reservoirs were classified as class II (good water, guidelines for this class are presented in Table 3). Class II of water means that the value of the parameters of water quality indicate slight anthropogenic influences. The quality of water from the Dąbski Reservoir was considered ‘unclassifiable’ with the values of phosphates falling into V class (bad quality) in winter and COD falling into III class in autumn. Class V of water means that there is a serious deviation from the natural condition. Slightly greater pollution than in the Dąbski Reservoir was detected in the Tyniec Reservoir water. The quality of water was considered ‘unclassifiable’ with the values of conductivity and COD falling into class III and chlorides into class V in all of the seasons of the year. Relatively high values of parameters either in two of the above mentioned reservoirs resulted from relatively high anthropopressure. These reservoirs were located near the main roads where runoff may have caused deterioration of physico-chemical properties. The Dąbski Reservoir is situated close to the expressway. The Tyniec Reservoir is located near the ring road. Fuel spillages and road salting are the primary causes of this water pollution.

Table 3

Average yearly water quality in the Cracow reservoirs

Reservoir	pH	Total hardness [mgCaCO$_3$/dm^3]	Conductivity [µS/cm]	COD [mgO$_2$/dm^3]	Chlorides [mgCl/dm^3]	Ammonium [mg/l]	Nitrites [mg/dm^3]	Nitrates [mg/dm^3]	Phosphates [mg/dm^3]
good quality limits (class II)	6.0–8.5	100	1000	6	200	1	0.1	15	0.4
Bagry	I	I	II	II	II	I	I	I	I
Nowohucki	I	I	I	II	I	I	II	I	II
Płaszowski	I	I	II	II	II	I	I	I	Uncl. (V)
Dąbski	I	I	II	Uncl. (III)	II	I	I	I	Uncl. (V)
P.Rusiecki	I	I	I	II	II	I	II	I	I
Tyniec	I	I	Uncl. (III)	Uncl. (III)	Uncl. (V)	I	II	I	II
Zakrzówek	I	I	II	I	I	I	I	I	I
Zesławice	I	I	I	I	I	I	II	II	Uncl. (V)

High values of the analysed parameters were also registered in the Płaszowski and Zesławice Reservoirs (Table 3). The concentration of phosphates in the Płaszowski Reservoir placed its water as class V during winter and three other parameters (conductivity, chlorides, COD) as class II. Water in the Zesławice Reservoir was classified as class V, as was determined by phosphates in winter, whereas nitrites and nitrates caused it to be classified as class II. The reason for this may be the built-up city housing areas and sewage disposal in the reservoir catchment area. In these reservoirs, apparent signs of degradation have been revealed which result in high concentrations of chlorides, phosphates, COD value and conductivity. However, the COD value and concentrations of phosphates were characterised by the highest annual fluctuation.

The results for water samples taken from the reservoirs in Tyniec and Zesławice are presented in Fig. 2. In Tyniec Reservoir the COD value was the highest whereas in the

Zesławice Reservoir, it was the lowest. The maximum COD values were observed in summer (unclassifiable – class III) while in autumn and winter, smaller values appeared (class II). The value of this parameter in the Zesławice Reservoir belonged to class I (< 3mgO_2/dm^3). It should be noticed that a higher COD value means higher levels of contamination with organic substances; therefore, the reasons for concentrations that are that high could be attributed to surface runoff or infiltration of pollutants from agricultural areas. High COD values in summer may also be related to the blooming of phytoplankton, fluctuating nutrient delivery from the reservoir catchment or be an effect of growing season.

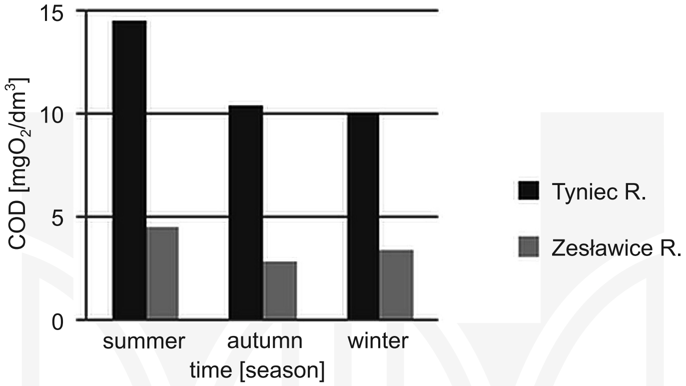

Fig. 2. Seasonal variability of COD in the Zesławice and Tyniec Reservoirs

As with the large majority of water bodies in a temperate climate, the aquatic primary production in the studied reservoir is limited by phosphorus. Seasonal phosphate distribution in the Płaszowski and Przylasek Rusiecki Reservoirs is presented in Fig. 3. In the the Płaszowski Reservoir the concentration of phosphates was the highest while in the Przylasek Rusiecki Reservoir, it was the lowest. The concentration of phosphates in the Przylasek Rusiecki Reservoir belonged to class I. The values were significantly exceeded in the

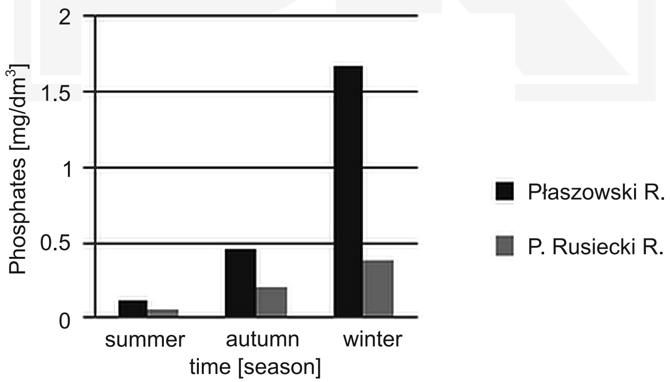

Fig. 3. Seasonal variability of phosphates in the water of the Przylasek Rusiecki and Płaszowski Reservoirs

Płaszowski Reservoir during autumn (0.46 mg/dm^3 – II class) and winter (1.67 mg/dm^3 – V class). A significant increase of phosphate levels was observed during winter sampling, while phosphate concentrations decrease during vegetation season. The ionic nitrogen $N-NO_3^- + N-NO_2^-$) to phosphates $(P-PO_4^{-3})$ ratio during summer and autumn was within the range of 7:1–8:1, while during winter, it was largely in excess of the phosphorus demand of freshwater plant life (2:1 and below) [11].

The water quality parameters for the investigated reservoirs were also checked against the Ministry of Health Regulation from 16th October, 2002 (requirements which should be met for the purposes of bathing). Only pH, COD, ammonium, nitrates and phosphates are mentioned in this regulation. All of these water reservoirs complied with the requirements for bathing quality with regard to the physico-chemical parameters in summer time. In autumn and winter, when the recreational season is over, the permitted concentration of nitrates was considerably exceeded in these reservoirs. The situation was similar for phosphates in the water of the Płaszowski Reservoir, the Dąbski Reservoir and the Zesławice Reservoir (Table 3).

To assess the quality of the habitat for fish, the selected physicochemical parameters were also checked against with the Ministry of the Environment Regulation from October 4, 2002 (requirements which should be met for inland waters for fish habitats in the wild). For the studied reservoirs, only nitrates (III) were significantly exceeded in the waters of the Nowohucki and Przylasek Rusiecki reservoirs in all of the seasons. Due to these high concentrations, these two reservoirs are not suitable as fish habitats (Table 4).

Table 4

Cracow reservoirs according to the bathing quality and the fish habitat for the whole year (+suitable, - not suitable)

Reservoirs	Bathing	Fish habitat
Bagry	+	+
Nowohucki	–	–
Płaszowski	–	+
Dąbski	–	+
P.Rusiecki	+	–
Tyniec	+	+
Zakrzówek	+	+
Zesławice	–	+

6. Conclusions

To sum up, most of the Cracow reservoirs fulfilled the conditions to rate them as class II which means that the surface waters were of good quality. Waters were classified as practically unpolluted. The values of water quality indicators showed a low effect of anthropogenic impact. Four reservoirs had unclassifiable water quality only in winter. The Tyniec Reservoir had an unclassifiable water quality in all of the seasons of the year. Their location had the highest impact on deterioration of the physico-chemical properties. For example, the Płaszowski Reservoir was located near a busy street and railway line. Furthermore, the Zesławice Reservoir, receiving most of the contamination from the Dłubnia River, is located near a frequently used street. Only two reservoirs (the Nowohucki and Przylasek Rusiecki Reservoirs) were not suitable as fish habitats in all the seasons of the year. These were often restocked and used for fishing. However, only in the summertime were these waters suitable for bathing because only at this time did indicators reach a value below the limit.

In general, the water quality has been substantially deteriorated by the inflow of pollutants from local sources (e.g. use of fertilizers), point (e.g. wastewater discharges) or linear (e.g. runoff pollution from roads). This has had a major impact on the environment. Therefore, the monitoring of water quality should be maintained in future seasons.

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