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Seasonality of the basic physical and chemical characteristics of water flowing through the cascades of small reservoirs in urban and suburban areas

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Abstract: The paper showed the changes of characteristics of river water flowing through the cascades of reservoirs. One of the cascades is located in a highly urbanized area of Lodz. The second is in a suburban area on the northern outskirts of Lodz agglomeration. However, it still remains under the influence of storm water discharged from the highway. Every 2 weeks, in 4 monitoring points (on the input and on the output of each cascade), the measurements of basic physical and chemical water parameters were made (using data registered in cross-sections obtained between 2006 and 2012). The analysed characteristics can be divided into three groups: 1. No changes in the seasonal fluctuations of analysed characteristics before and after the cascade of reservoirs and no differences between urban and suburban areas in the influence of the cascades on river water; 2. Significant changes in the seasonal fluctuations of analysed characteristics before and after the cascade of reservoirs and no differences between urban and suburban areas in the influence of the cascades on river water; 3. Significant changes in the seasonal fluctuations of analysed characteristics before and after the cascade of reservoirs and also significant differences between urban and suburban areas in the influence of the cascades on river water. The first group includes the temperature and pH of the water, the second group water conductivity and the third group water turbidity and dissolved oxygen in water.

Key words: water quality, ponds, seasonal fluctuations, anthropopression, urban area

Introduction

The positive impact of small flow-through reservoirs on the quality of river water is well-known (Straškraba 2005; Pietruszyński et al. 2012). In spite of their scenic and retention functions (runoff compensation) they often create a specific biochemical barrier to sewage and biogenic substances coming from the areas strongly transformed by humans. That is why they are often created in small urban streams, characterized by a high irregularity of runoff and poor water quality. Cascades of reservoirs reduce the dispersion of runoff and, in principle, improve water quality in the river (Straškraba 2005; Ji 2008).

The authors set out to test changes in the level and seasonal fluctuations of some of the basic physical and chemical characteristics of the river water flowing through a cascade of several reservoirs. One of the cascades is located in a highly urbanized area of Lodz. The second is in a suburban area on the northern outskirts of Lodz agglomeration. However it still remains under the influence of storm water discharged from the highway.

Methods and study area

Lodz is a city which does not have any big rivers. However, there are many small flows, changed by human activities. Numerous small reservoirs of different functions have been built in their catchments. One of the small rivers in Lodz is the Sokolowka draining the northern part of the city (Fig. 1). Its catchment mainly consists of Wartanian clays, dominant in the upper and middle parts and the glacifluvial sands occurring mostly in the lower part and coming from the same period. The valley is lined with gravels, sands and other alluvium sediments coming from Vistula glaciations or Holocene (Bartnik at al. 2008).

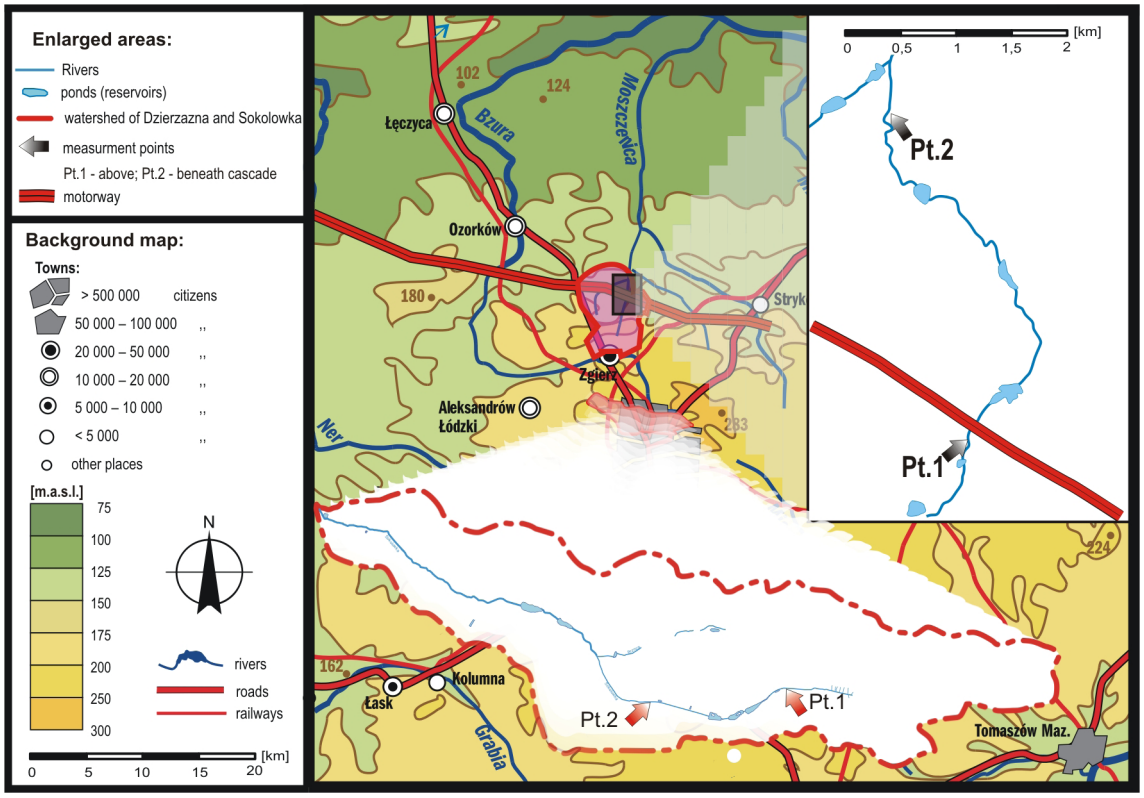


Fig. 1. Location of studied catchments

The vast majority of them have good permeability, but it should be remembered that in many places there are anthropogenic layers deposited on the natural sediments and they are characterized by diverse but mostly poor permeability. In the Sokolowka catchment, there is a cascade of three flow-through reservoirs (the Upper Julianow, the Lower Julianow and Zgierska) and one pond, which is placed on the right river bank (Table 1). The pond, in normal conditions (except during flooding) is directly fed with river waters. Part of the catchment in which the cascade of reservoirs is located is characterized by densely built detached houses. Only in the close vicinity of the river are there parks and recreational areas.

In the suburbs of Lodz agglomeration, within the Lodz hills, is the Dzierzazna catchment with an area of 42.9 km^2 (Fig.1). The area of the Dzierzazna basin clearly descends in the northern direction, and among the deposits forming its surface silts, sands, gravels (lower and middle part of the catchment) and drift clays (southern part) dominate (Jokiel 2002). Agricultural lands are predominant here. Unfortunately, none of the villages within the catchment area possesses a sanitary sewage system. It is worth mention-

Table 1. Parameters of flow-through reservoirs in research catchments

Catchment	Reservoir	Area	Mean depth	Volume
		[×10^3 m^2]	[m]	[×10^3 m^3]
Sokolowka (urbanized)	Julianow Gorny	16.4	1.37	22.5
	Julianow Dolny	10.8	1.03	11.1
	Zgierska	17.0	1.35	23.0
Dzierzazna (suburban)	Dabrowka Przylesie	19.2	0.39	7.5
	Glowa	15.2	0.50	7.6
	Biala	9.3	1.45	13.5

ing that about 2 thousand contamination hotbeds have been identified in this area (septic tanks, cesspits, sewage outlets). The road network, any modifications connected with the building of new dwelling houses and the A2 highway, which is currently under construction (Emilia-Strykow) and which bisects the catchment area longitudinally, all play an important role in the transformation of the physico-chemical water properties of the Dzierzazna basin. The cascade of reservoirs is located in the lower part of the catchment, below the A2 motorway and consists of three flow-through ponds situated at a distance of about 3 km (Table 1).

Every 2 weeks, in 4 monitoring points (on the input and on the output of each cascade), the measurements of basic physico-chemical water parameters were made (Dojlido 1995): water conductivity, acidity, temperature, dissolved oxygen concentration (investigated electrochemically) and turbidity (measured with the nephelometric method). In this work the data registered in cross-sections obtained between 2006 and 2012 has been used.

Results and discussion

Water temperature

Flow-through reservoirs significantly influence stream temperature changes. The waters flowing out of the ponds are warmer in comparison with the waters flowing into the reservoirs (Jaguś and Rzętała 2008). This pattern can be observed in the case of both cascades of reservoirs (annual average of 2°C in the case of the Sokolowka cascade and 1.4°C in the case of the Dzierzazna cascade; Fig. 2). However, the magnitude of the temperature increase is not the same for all seasons. The heating up process is observed mainly in the winter half-year in the case of the Sokolowka cascade of reservoirs. In summer the waters flowing out of the reservoirs have slightly lower temperatures. The temperature decrease of the discharging waters below the ponds in comparison with the waters feeding the cascade is registered from April till July. In August the temperatures are almost identical for waters above and beneath the cascade, while from September to March a significant increase is recorded.

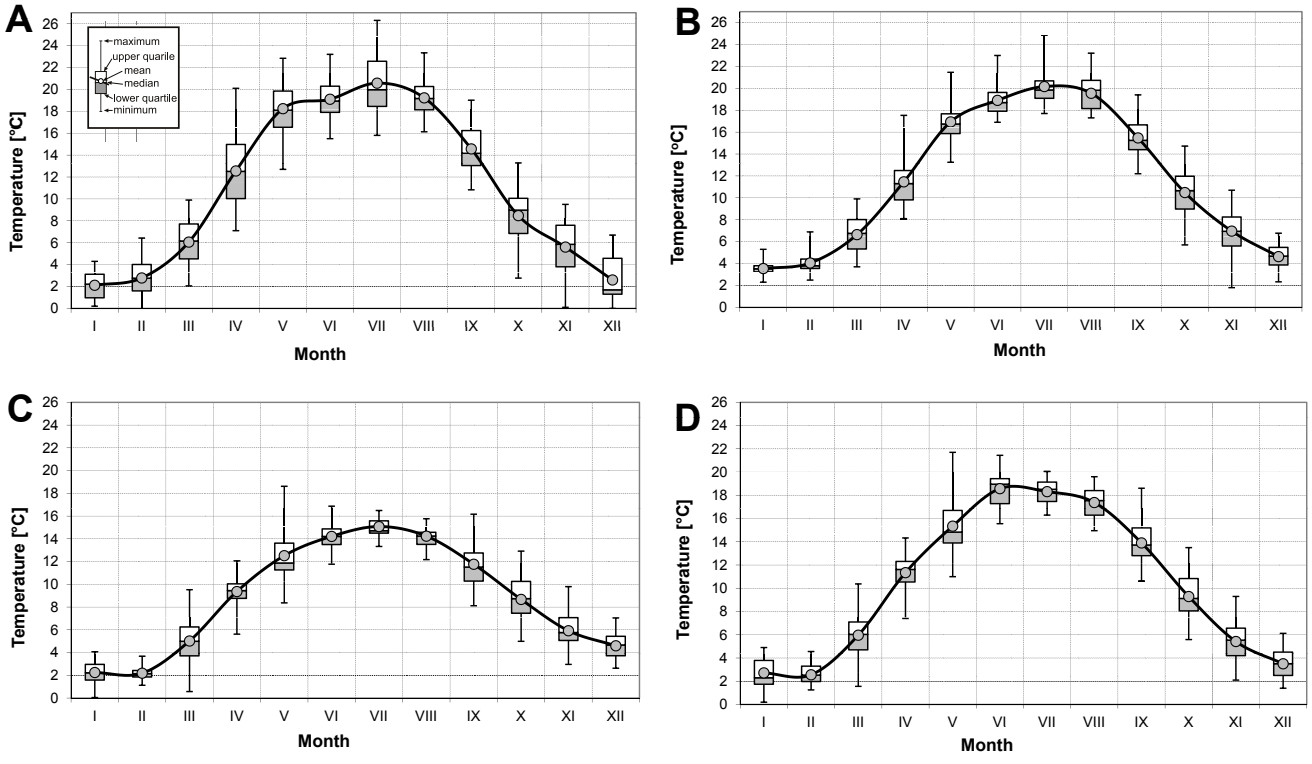


Fig. 2. Seasonal fluctuation of water temperature: A – above the urban cascade; B – beneath the urban cascade; C – above the suburban cascade; D – beneath the suburban cascade

In the case of the cascade of reservoirs on the Dzierzazna river, a period of lower temperatures beneath the ponds falls only in November and December. It is due to the decidedly greater flow and larger shadow on the riverbed than in the Sokolowka river (Bartnik and Moniewski 2011). Therefore, the water is not so exposed to direct solar radiation. This results in lower water temperatures in the river above the cascade of reservoirs almost all year round. Higher water temperatures in the river above the ponds occur only in late autumn and early winter. The temperature of the shallow groundwater drained by the Dzierzazna river is high during this time (more than 9°C; Tomalski 2012), and the air temperature affecting water temperature in ponds is low.

The changes in water temperatures which were depicted above do not cause the modifications in the seasonal distribution of this characteristic. The temperature maximum fell in both cases in June or July, while the minimum temperatures fell in January or February. However, in case of the Sokolowka cascade the amplitudes of temperature fluctuations of waters below the reservoirs decrease by about 2°C. The temperature dispersion decreases (shown in the figures as the length of the whiskers) in particular months in both cases, although the periods of the largest (April or May) and the smallest (January or February) differences between the measurements stay constant. It is a consequence of the huge thermal capacity and thermal inertia of water.

pH.

It is commonly regarded that pond water is alkalized, as a result of reservoirs' eutrophication. The process is particularly intense in summer (Rzętała 2008). However, this phenomenon has not been observed for the cascades of reservoirs on the Sokolowka and Dzierzazna rivers (Fig. 3). The observation results rather indicate that the waters are neutralized or even acidified, because the average pH of the outflows below the cascade is equal to 6.86 in the Sokolowka and 6.77 in the Dzierzazna, while the average pH of the feeding waters flowing into the pond at the cascade top is 6.91 in the Sokolowka and 7.21 in the Dzierzazna. In the case of the Sokolowka cascade of reservoirs the observed differences are so small that it could be

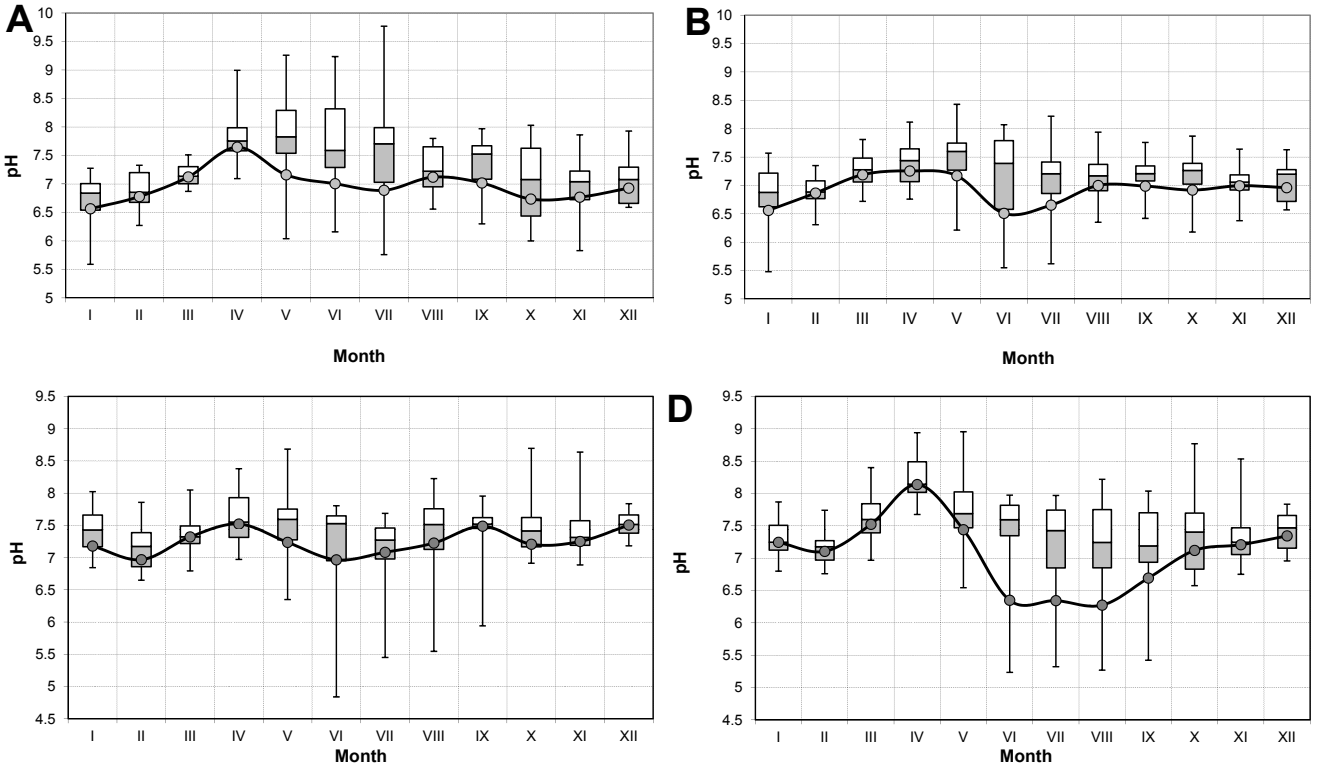


Fig. 3. Seasonal fluctuation of water pH: A – above the urban cascade; B – beneath the urban cascade; C – above the suburban cascade; D – beneath the suburban cascade

stated that there is no impact of reservoirs on the pH of stream waters. There is an opposite situation in the case of the cascade of reservoirs on the Dzierzazna river. The difference here is significant and amounts to half a pH unit. Such a differentiation is influenced by the inflow of strongly alkaline waters coming in winter from the highway dewatering system (even up to 10.8).

The cascade of ponds does not interrupt the seasonal fluctuations of water pH. The most alkaline water, relatively speaking, is received in April or May, while slightly acidic water is obtained in January and February. Water pH dispersion is also significantly higher in the warm half of the year. Slightly acidic waters appear above and beneath the ponds in the warm period. They have an influence on mean value but do not change the median level. These waters are clearly noticeable in the case of ponds in the Dzierzazna catchment and are associated with the discharge of a large amount of storm water from sealed areas of Lodz (Sokolowka catchment) or the motorway (Dzierzazna catchment).

Dissolved oxygen

The amount of oxygen dissolved in water depends on the characteristics of the pond and its construction. Undoubtedly, if the water flows out from the reservoir through a damming structure (weir, etc.) and it freely flows down the height, it is mechanically oxygenated. However, there is no evidence what kind of impact the reservoirs have on the amount of dissolved oxygen in water. Some authors (Rzętała 2008) think that the eutrophicated ponds increase the amount of oxygen (the effect of photosynthesis). Others claim that the reservoirs play an oxygen reducing role, due to the oxygen consumption in the processes of organic matter decay (Mioduszewski 2007). It should be pointed out that this influence does not only depend on the development of flora (including algae blooming), but also on the ponds' depth, capacity, water flow velocity (speed of water regeneration) and the whole spectrum of physico-chemical characteristics of the reservoir feeding water. The vast number of contributory factors leads to the conclusion that the way of influencing the amount of oxygen is more related to the local conditions in which the pond is functioning rather than the regularities which can be observed in particular cases.

The different impact of the cascade of reservoirs on the dissolved oxygen level in water is evident in the case of the analysed catchments. The cascade of water ponds on the Sokolowka river causes an increase in the amount of dissolved oxygen in river waters beneath it of about 3% on average in a year (Fig. 4 a,b) but the cascade of reservoirs on the Dzierzazna river causes a decrease in this characteristic of about 2% (Fig. 4 c,d). In the case of the Sokolowka catchment greater oxygen concentration is registered in the warmer season beneath and above the cascade. In the Dzierzazna catchment greater oxygen concentration is registered in the warmer season above the cascade and in the colder season beneath it. However, it should be mentioned that in the case of both systems, in the warm part of the year (from May till September) the amount of oxygen in the waters beneath the cascade is smaller than in the waters flowing into the reservoirs. It may be linked to the usage of some of the oxygen produced by plants in the decomposition of organic matter deposits. In colder seasons the impact of the mechanical enrichment of water flowing through damming constructions is more evident. Interestingly, the relative higher oxygen concentration in water (if we compare water flowing into and out of the cascade) is always related to the higher water temperature. In summer, water feeding the cascade reservoirs is warmer and more oxygenated, while in winter, water flowing out is warmer and has more dissolved oxygen. The question remains open as to whether this dependence is coincidental or whether it is some kind of regularity.

The seasonal pattern of the changes in the amount of dissolved oxygen in water above the cascade is quite similar. Two periods characterized by the maximum values can be clearly distinguished: spring and summer seasons separated by a local minimum in June (according to the authors its genesis is difficult to explain). In the case of the Sokolowka catchment the maximum values are similar in both seasons, while in the case of the Dzierzazna catchment, the summer maximum is greater. Taking into account the discharging water, the second maximum is lower or even does not exist (in the case of the Dzierzazna catchment). It is presumably caused by the oxygen demand of reduction processes.

Water conductivity

It is known that reservoirs decrease the amount of substances being dissolved in water (Dondajewska 2007; Eiseltová 2010; Persson 2012). At the same time, with the reduction we observe a decrease in electrical conductivity. In cases where ponds are under strong

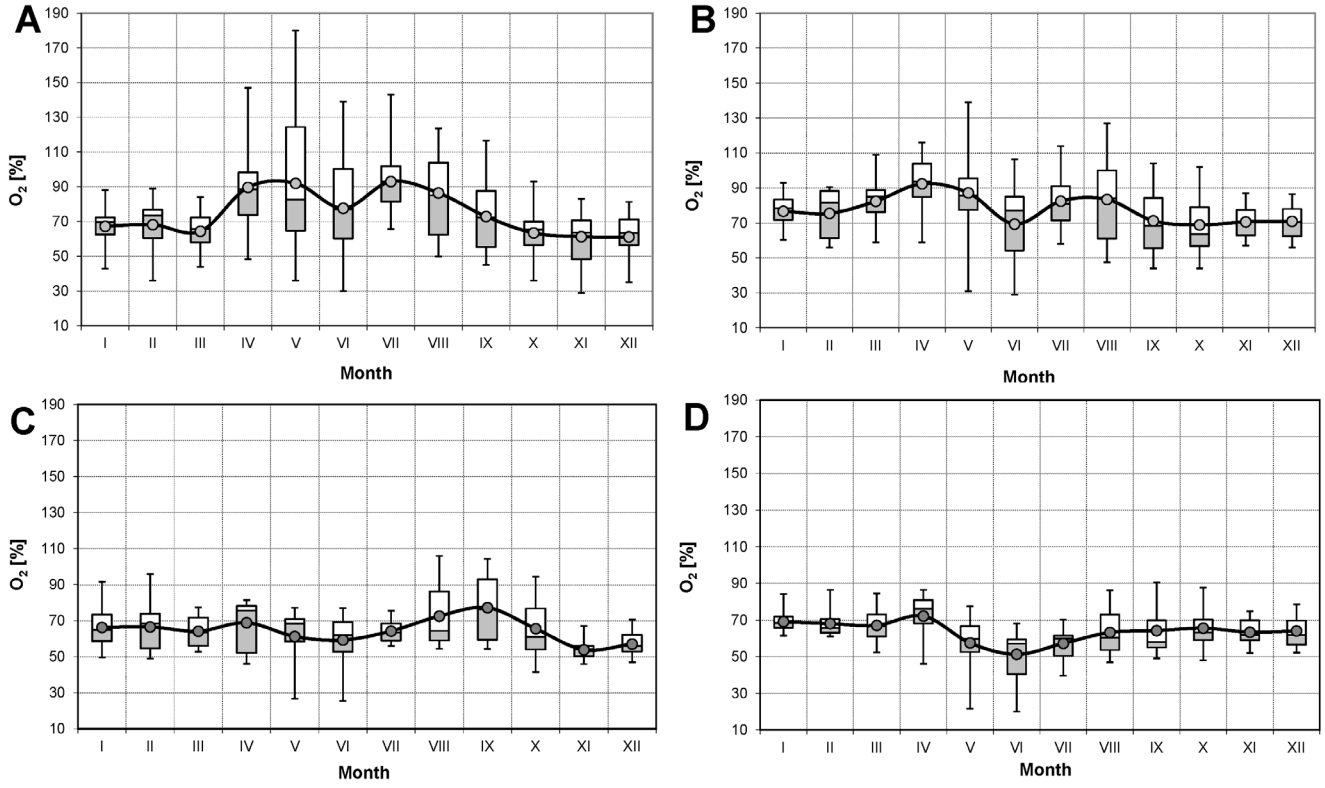


Fig. 4. Seasonal fluctuation of dissolved oxygen in water: A – above the urban cascade; B – beneath the urban cascade; C – above the suburban cascade; D – beneath the suburban cascade

anthropopression, a great deal of waste flowing into the stream or directly to the pond is captured. Therefore, it is expected that in urban basins the greatest water conductivity is registered in winter, when large amounts of chlorides are used to reduce the "slipperiness" of icy streets and pavements.

The research on the impact of the reservoir cascade on the electrical conductivity of the Sokolowka stream waters showed that the maximum SEC values are observed in winter (Fig. 5 a,b) and are related to the inflow of waste coming from the winter upkeep of road surfaces. During summer some of these substances are absorbed by water plants or become decomposed. It can be clearly seen that the amount of waste flowing out of the ponds to the stream is significantly reduced.

The cascades of reservoirs compared here behave differently in spring (April, May). The city ponds, loaded with pollution in winter, are "flushed" in spring. Only during those two months the water flowing out of the pond cascade has greater electrical conductivity than the water feeding it. At the same time beneath the suburban cascade there is a minimum level of water conductivity. It receives a much lower pollution load in winter than the urban cascade of reservoirs. Simultaneously, in spring groundwater inflow to reservoirs and the river is greater (the urban riverbed is mostly sealed), and the quality of drained groundwater is much better. Average groundwater conductivity in the Sokolowka catchment is higher by about 200 μS cm^{-1} than in the Dzierzazna catchment (Tomalski 2012).

Water turbidity

Ponds built on small rivers decrease the water turbidity (Oleś and Szlęk 2004). However, when water ponds are very fertile and eutrophic, during the algal blooming period, water turbidity significantly increases. Hence, the reservoirs reduce mainly the amount of allochtonic matter, which is at the same time the source of new suspensions. That is how they influence the optical parameters of discharging waters (Rzętała 2008). This means that the minimum water turbidity fell in the winter half-year.

The turbidity of river water is strictly bound to the magnitude and mainly to the velocity of the river water flow. Higher turbidity is characteristic for the months with poor flora development (from Novem-

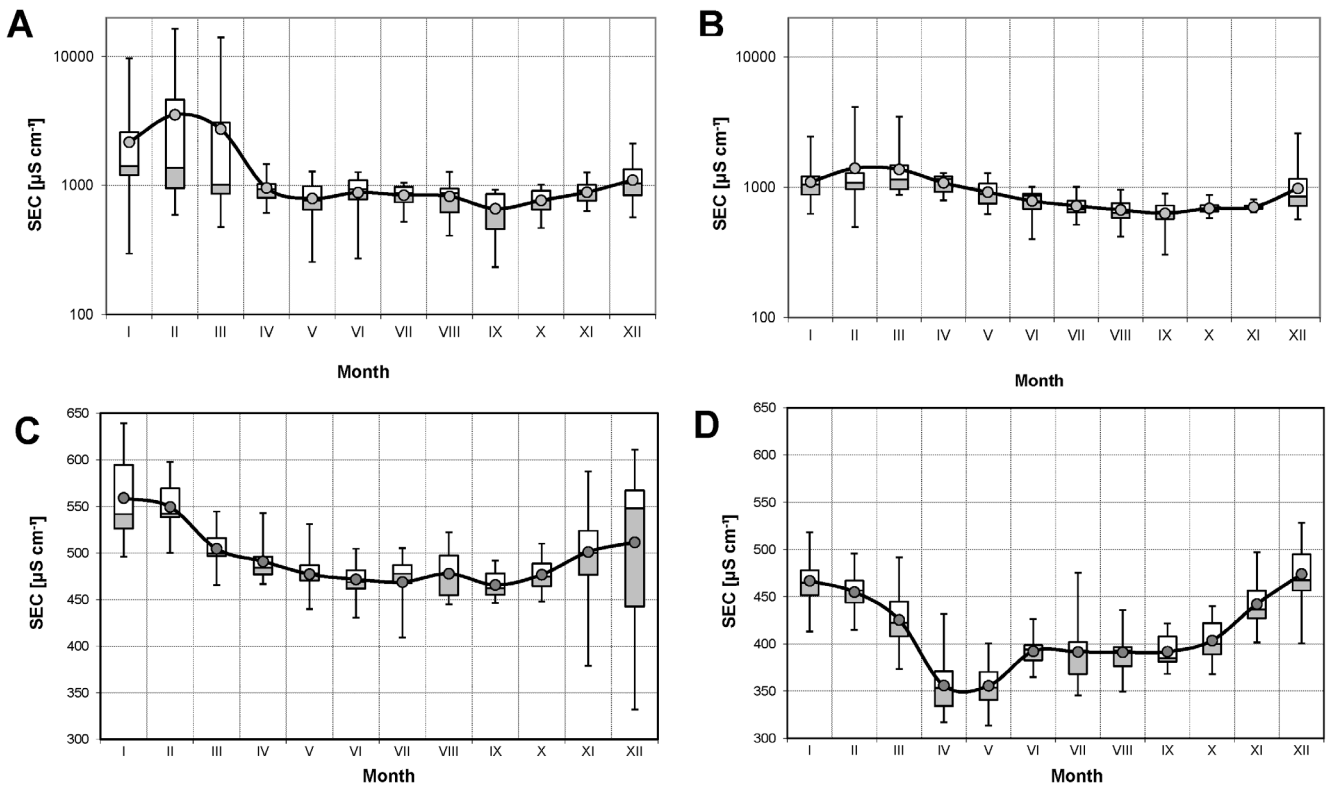


Fig. 5. Seasonal fluctuation of water conductivity: A – above the urban cascade; B – beneath the urban cascade; C – above the suburban cascade; D – beneath the suburban cascade

ber till March), while the rainfall and melting waters feeding the river have a greater amount of suspended matter (Fig. 6). A similar situation occurs during the heavy precipitation periods (June and July) that cause the appearance of surface runoff and the increase in river water streamflow within the river bed.

The cascade of reservoirs located in the suburban area can handle the reduction in water turbidity (in December by as much as seven times) through suspension deposition at the pond bottom. Simultaneously as a result of phytoplankton blooming, the water turbidity beneath the cascade of ponds is greater during the vegetation period. This is consistent with the views of Rzętała (2008).

In the urban area the cascade of ponds reduces the level of water turbidity in the cold period of the year, but its level is still high. It is linked to the discharge process of huge amounts of substances needed for maintaining roads in good condition. In small urban catchments the density of outlets of rainfall collectors discharging to the stream may be very high. They are frequently situated along the river course, and also between reservoirs creating the cascade. In such cases the impact of forebays on water turbidity may be limited. In the warmer half-year, the water from rainfall collectors causes "flushing of" ponds. This is the reason for the formation of a local minimum in June and July.

Conclusions

Cascades of reservoirs influence the basic physical and chemical characteristics of river waters and their seasonal distribution in a range of ways. The smallest modifications are clearly visible in the case of characteristics which are affected by large-scale factors (for example water temperature). The greatest change is noted in the case of parameters highly dependent on local conditions (for example oxygen dissolved in water).

The paper analysed the changes in characteristics of river water caused by the cascades of reservoirs in two aspects: seasonal fluctuation and similarity between urban and suburban areas. The analysed variables can, therefore, be divided into three groups:

1. No changes in the seasonal fluctuations of the analysed characteristics before and after the cascade of reservoirs and no differences between urban and

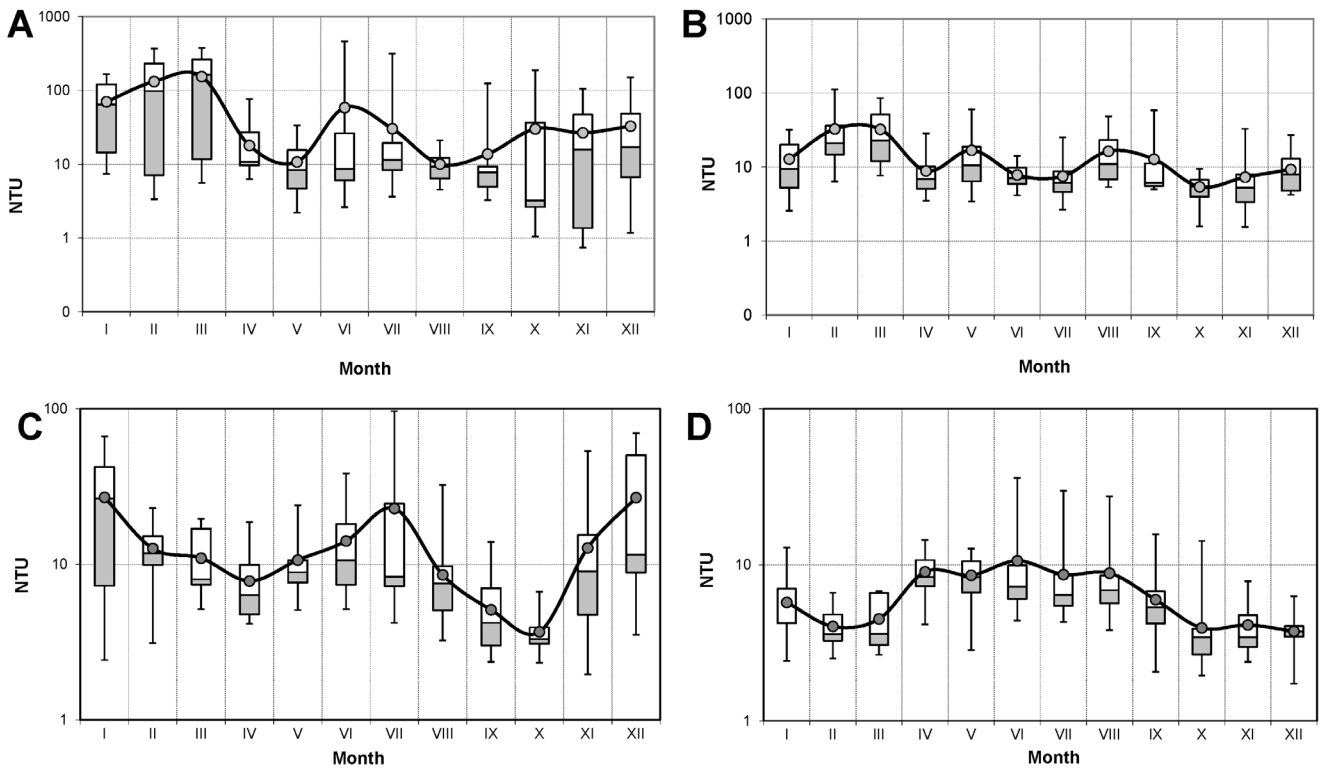


Fig. 6. Seasonal fluctuation of water turbidity. A – above the urban cascade; B – beneath the urban cascade; C – above the suburban cascade; D – beneath the suburban cascade

suburban areas in the influence of the cascades on river water;

2. Significant changes in the seasonal fluctuations of the analysed characteristics before and after the cascade of reservoirs and no differences between urban and suburban areas in the influence of the cascades on river water;
3. Significant changes in the seasonal fluctuations of the analysed characteristics before and after the cascade of reservoirs and also significant differences between urban and suburban areas in the influence of the cascades on river water.

The first group includes the temperature and pH of water. The cascades of reservoirs modify the value of these characteristics (increase the temperature and neutralize or even slightly acidify water) but there are no changes in their seasonal fluctuations. This influence seems to be independent of the level of anthropopression in the catchment.

The second group includes the water conductivity. The presence of a cascade of reservoirs along the river reduces its degree, but does not change seasonal fluctuations of this characteristic. However, a reduction in solutes in water depends on human activity in the catchment (volume of pollution intake to the surface and underground waters, level of riverbed modification, etc.).

The third group includes characteristics which are most strongly dependent on local conditions (water turbidity and dissolved oxygen in water). Water turbidity is reduced in both cases but there is no significant level of this reduction in the urban catchment due to the large number of outlets of rainfall collectors. They are located in various places along the river (between the ponds too), which considerably reduces the efficiency of the cascade. The level of dissolved oxygen in water beneath the cascade of reservoirs increases in the urban catchment, but decreases in the suburban catchment. In the case of the water turbidity and the level of dissolved oxygen in water, the efficiency of ponds depends largely on the level of the catchment development. In the case of dissolved oxygen it also depends on the way the ponds are emptied (the possibility of mechanical oxygenation of water).

The presence of a cascade of reservoirs on a river increases the level of river water quality. The exam-

ple of two cascades of ponds in Lodz and nearby areas shows that the improvement in the characteristics of water quality depends on the level of anthropopression noticed in the catchment (3 out of 5 cases). The studies included only two catchments and for this reason the results of the research should not be generalized. However, the authors believe that the outcomes are interesting and it is worth extending these studies to other catchments functioning in different geographical conditions.

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References

Bartnik A., Moniewski P., 2011, River Bed Shade and Its Importance in the Process of Studying of the Fundamental Physico-Chemical Characteristics of Small River Waters, [in:] Glińska-Lewczuk K. (ed.), Contemporary problems of management and environmental protection. Vol. 7: Issues of landscape conservation and water management in rural areas, Wyd. UWM, Olsztyn: 137-149.

Bartnik A., Moniewski P., Tomalski P., 2008, Rola naturalnych i antropogenicznych elementów obiegu wody w zlewni miejskiej (Sokołówka) i podmiejskiej (Dzierżązna) (The role of natural and anthropogenic elements in water circulation in urban (Sokolowka) and suburban catchment (Dzierzazna)), [in:] Bródka S. (ed.), Problemy Ekologii Krajobrazu. T 22: Problemy środowiska przyrodniczego miast, Wyd. Nauk. Bogucki, Warszawa-Poznań: 39-48 (in Polish).

Dojlido J. R., 1995, Chemia wód powierzchniowych (The chemistry of surface water), Wyd. Ekon. i Środ., Białystok, p. 344 (in Polish).

Dondajewska R., 2007, Effect of restoration of a lowland dam reservoir on river water quality, Limnol. Rev. 7(4): 185-190.

Eiseltová M., 2010, Restoration of Lakes, Streams, Floodplains, and Bogs in Europe. Principles and Case Studies, Springer, Dordrecht-Heidelberg-London-New York, p. 374.

Jaguś A., Rzętała M., 2008, Znaczenie zbiorników wodnych w kształtowaniu krajobrazu (na przykładzie kaskady Pogorii) (The importance of water reservoirs for shaping landscapes. Pogoria cascade case), ATH-UŚ, Bielsko-Biała-Sosnowiec, p. 152 (in Polish).

Ji Zhen-Gang, 2008, Hydrodynamics and water quality: modeling rivers, lakes, and estuaries, Wiley, Hoboken, p. 676.

Jokiel P., 2002, Woda na zapleczu wielkiego miasta (Water in the hinterland of a big city), Wyd. IMGW, Warszawa, p. 148 (in Polish).

Mioduszewski W., 2007, Budowa stawów (The construction of ponds), Oficyna Wyd. „Hoża", Warszawa, p. 118 (in Polish).

Oleś W., Szlęk R., 2004, Zmiany jakości wody zbiornika Nakło-Chechło w latach 1991-2000 (The changes in the quality of water of the Nakło-Chechło reservoir), [in:] Jankowski A., Rzętała M. (eds.), Jeziora i sztuczne zbiorniki wodne: funkcjonowanie, rewitalizacja, ochrona (Lakes and reservoirs: functioning, rehabilitation and protection), Wyd. UŚ, Sosnowiec: 165-172 (in Polish).

Persson J., 2012, Urban lakes and ponds, [in:] Bengtsson L., Herschy R.W., Fairbridge R.W. (eds.), Encyclopedia of Lakes and Reservoirs, Springer, Dordrecht-Heidelberg-New York-London: 836-839.

Pietruszyński Ł., Olszewska A., Bogdanowicz R., 2012, The assessment of the impact of retention reservoirs on the water quality of streams in urban areas (Oruński Stream catchment case), Limnol. Rev. 12(2): 87-92.

Rzętała M., 2008, Funkcjonowanie zbiorników wodnych oraz przebieg procesów limnicznych w warunkach zróżnicowanej antropopresji na przykładzie regionu górnośląskiego (The functioning of water reservoirs and the course of limnic processes in different anthropopression conditions: the case of Upper Silesia), Wyd. UŚ, Katowice, p. 172 (in Polish, English summary).

Straškraba M., 2005, Reservoirs and other Artificial Water Bodies, [in:] O'Sullivan P.E., Reynolds C.S. (eds), The lakes handbook. Vol. 2: Lake restoration and rehabilitation, Blackwell, Oxford: 300-328.

Tomalski P., 2012, Sezonowość wybranych charakterystyk fizykochemicznych wód podziemnych w dolinie małej rzeki miejskiej na przykładzie Sokołówki (Łódź) (Seasonal fluctuations of selected physical and chemical characteristics of groundwater in the valley of a small city river. Sokołówka case study – Łódź), [in:] Marszelewski W. (ed.), Gospodarowanie wodą w warunkach zmieniającego się środowiska (Water management in conditions of the changing environment), Monografie KH PTG 1, Wyd. UMK, Toruń: 187-199 (in Polish).