

EFFECT OF AGRICULTURAL AND URBAN ECOSYSTEMS ON CONCENTRATION OF ORGANIC SUBSTANCES AND OXYGEN IN WATERCOURSE KADAŇ

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Abstract. The study investigates the influence of various ecosystems (agricultural vs. urban) surrounding a watercourse on the chosen indicators of water quality. In the years 1996–2001, water was sampled once a month from eleven cross-sections of the watercourse Kadaň and examined for the concentrations of dissolved oxygen, biodecomposable organic matter (BOD_5), and organic substances (COD_{Mn}). The mean values of the respective indicators in the research period were: $O_2 - 7.26 \text{ mg} \cdot \text{dm}^{-3}$, $BOD_5 - 2.12 \text{ mg} \cdot \text{dm}^{-3}$, $COD_{Mn} - 3.32 \text{ mg} \cdot \text{dm}^{-3}$. On average, the O_2 concentration was lowest in summer and autumn, most likely because of the intensive biological decomposition of organic matter, and had higher values downstream of agricultural areas than downstream of villages. BOD_5 was lowest in the months of January to March, whose thermal conditions were unsuitable for the decomposition of organic matter by microorganisms living in the stream, and highest in May. The indicator reached higher values downstream of villages and tended to fall on the segments surrounded with agricultural areas, suggesting that the self-purification of water took place there. COD_{Mn} was lowest in December to March, and highest in June to August. This indicator had higher values downstream of urbanised areas, which may be due to the discharge of raw sewage into the watercourse. As follows from the results, various ecosystems differently influence the indicators of surface water quality.

Key words: water quality, dissolved oxygen, organic substances

INTRODUCTION

The decomposition and mineralisation of organic matter regarded as a water pollutant are dissolved-oxygen-consuming processes. The most important sources of molecular oxygen in water are the atmospheric air over the water surface and the phytoplankton and

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green plants having assimilation ability. The amount of oxygen produced by green plants, particularly green algae, in the assimilation process depends on daily and seasonal factors, among them the amount and type of pollution. The oxygen content of surface water is highest in winter, in western Slovakia from December to February, and decreases with increasing temperature [Perháčová and Dovčiaková 2004]. The oxygen concentration varies also during the day, which corresponds with the changes in photosynthetic intensity and temperature (www.gabcikovo.gov.sk). Under natural conditions, the oxygen content of saturated water ranges between 7 and 15 mg · dm⁻³ [Tölgyessy and Blažej 1989]. The mean values determined by Noskovič et al. [2003] for a watercourse running in the Žitava river basin (from 9.73 to 10.96 mg · dm⁻³) fall within this range. Very low levels of dissolved oxygen in summer and autumn, observed by Liberacki [2003] in the stream Hutka, were found by him to have a negative effect on the quality of the stream water.

Organic matter in water undergoes oxidation in a biochemical or chemical way. Depending on whether the substances can be easily broken down by living organisms or not, they are classified as biologically decomposable, hardly biodecomposable or non-biodecomposable [Stred'anský 1999]. Since the determination of individual organic substances causes difficulty, some methods have been developed to determine the total concentration of such substances in water and to describe the total rate of water pollution. The most common methods include indirect ones based on the chemical or biological oxidation of organic material [Pitter 1999]. The chemical methods comprise oxidation with K_{Mn}O₄ (Kubel's method) or K₂Cr₂O₇ [Gábriš et al. 1998] and establish the chemical oxygen demand. COD_{Mn} is used for determining both biodecomposable and non-biodecomposable organic matter. Biodecomposable organic matter is also determined on the basis of the 5-day biochemical oxygen demand (BOD₅) [Pitter 1990].

The quality of surface and ground waters may be considerably impaired by agricultural and urban ecosystems. As a result of such deterioration, local water sources become gradually degraded which, in turn, decreases the attractiveness of the countryside to tourists and potential migrants from cities or from other regions. Most of rural districts in Slovakia do not have adequate financial resources to build their own water- and sewage-treatment facilities, hence they need support from European funds. It is therefore important for the local authorities to fully understand the factors contributing to the quality of water.

The present study aims to examine the effects of various ecosystems on the concentration of organic substances and oxygen in a small watercourse.

MATERIAL AND METHODS

The watercourse Kadaň, a left-bank tributary of the river Nitra, flows at the foothills of the Tribeč Mountains and has the springs situated in the village Štitáre (Fig. 1). Kadaň serves as a source of drinking water. The stream (19.4 km in length) runs through the agricultural and built-up areas of the villages Štitáre, Pohranice, Lapáš and Golianovo, passes by the village Veľký Cetín, and flows into the river Nitra. The drainage area of Kadaň (46.4 km²) is flat which makes it suitable for agricultural use. The largest tributaries are the channels Tichý, Betlemský and Veskejský which carry water to the reservoir built on Kadaň (in km 11.2) downstream of the village Golianovo. The water reservoir serves irrigation and fish-breeding purposes.

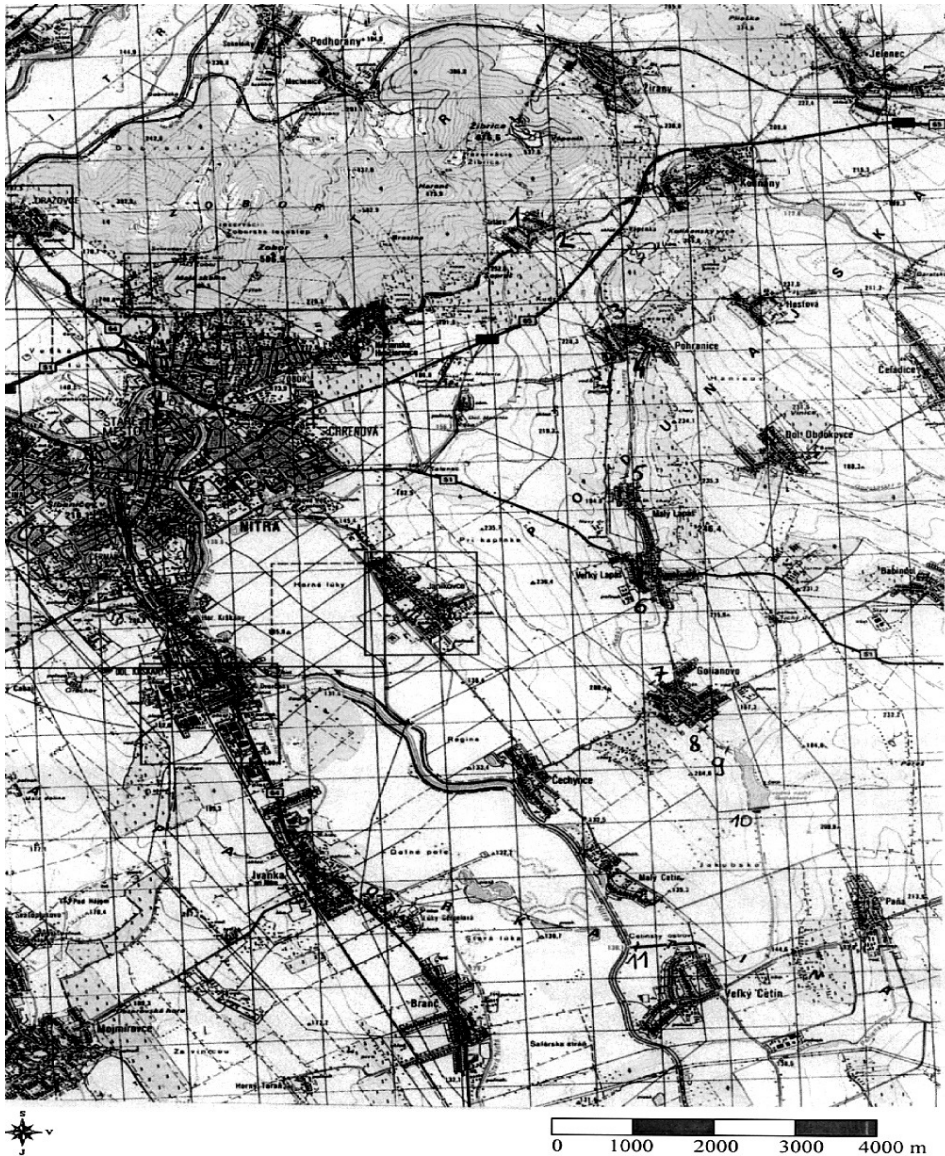
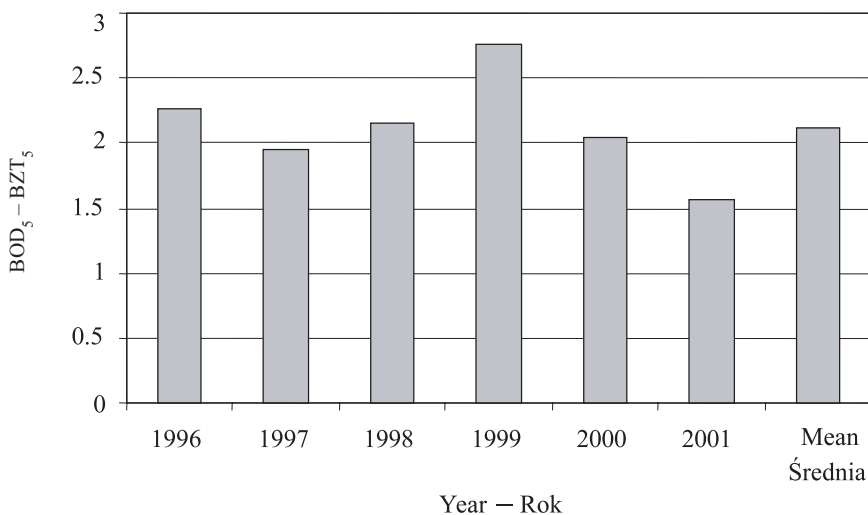
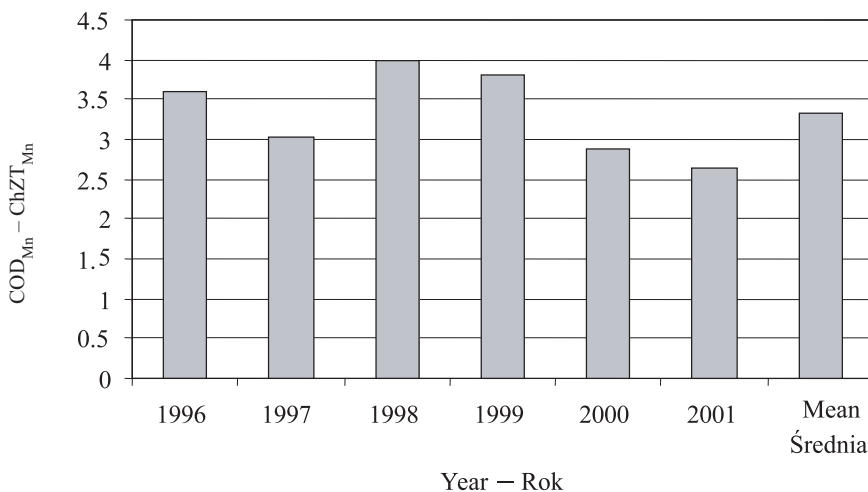


Fig. 1. Map of catchment of watercourse Kadaň (scale 1 : 100 000) showing water-sampling sites (No 1–11)

Rys. 1. Mapa zlewni cieku Kadaň (skala 1 : 100 000) z zaznaczonymi miejscami poboru prób wody (nr 1–11)

The area of interest lies on the Žitavská Upland, which is part of the vast Podunajská Plain, and has maize-beet-cropping soils. Throughout the catchment, highly plastic grey and blue-grey clays are deposited. A brown muck soil constitutes the top horizon. The subsoil in the area inundated by the river Nitra is formed by gravel levels.

Fig. 3. Mean values of BOD₅ (mg O₂ · dm⁻³) in study yearsRys. 3. Średnie wartości BZT₅ (mg O₂ · dm⁻³) w kolejnych latach badańFig. 4. Mean values of COD_{Mn} (mg O₂ · dm⁻³) in study yearsRys. 4. Średnie wartości ChZT_{Mn} (mg O₂ · dm⁻³) w kolejnych latach badań

Dissolved oxygen has a primary importance in the mineralisation of organic contaminants under aerobic conditions in the water self-cleaning process [Tölgýessy et al. 1984].

As shown in Figure 2, the mean concentrations of dissolved oxygen in the watercourse Kadaň ranged from 6.61 mg · dm⁻³ (year 2000) to 8.20 mg · dm⁻³ (year 1999), with the mean over the whole research period (1996–2001) being 7.26 mg · dm⁻³. To compare, the values measured by Kláneková [1997] in the lower part of the river Váh varied in a wider range, 7.5–11.0 mg · dm⁻³.

Sampling time was found to affect the concentration of dissolved oxygen: its mean values were usually lower in summer and autumn and higher in winter and spring (Fig. 5). The 1996–2001 mean of O_2 concentration was lowest ($5.91 \text{ mg} \cdot \text{dm}^{-3}$) in August, which obviously corresponds with an increased intensity of biochemical decomposition of organic matter in the watercourse. The amount of oxygen dissolved in water depends not only on its consumption in biological processes; it is also indirectly related to water temperature [Hudec 1996]. The oxygen solubility rate decreases with increasing temperature [Pitter 1999]. A decrease in the concentration of dissolved oxygen in a watercourse in summer months was also reported by Noskovič et al. [2003].

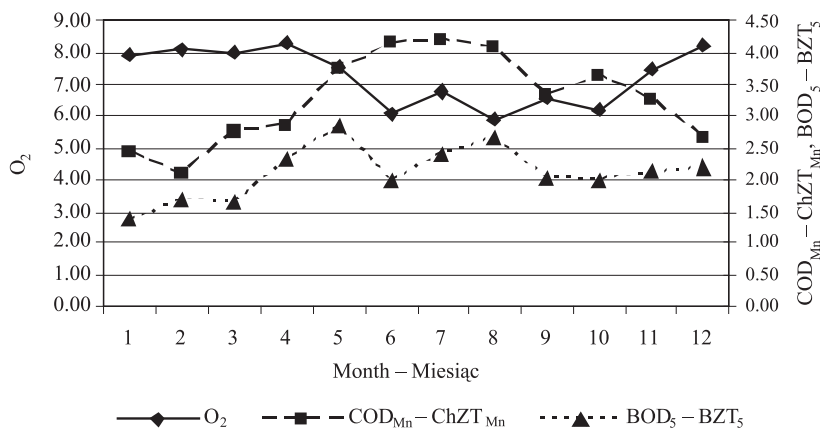


Fig. 5. Mean values of water quality parameters in study period (1996–2001) as dependent on sampling time (O_2 in $\text{mg} \cdot \text{dm}^{-3}$, COD_{Mn} and BOD_5 in $\text{mg} \text{O}_2 \cdot \text{dm}^{-3}$)

Rys. 5. Średnie wartości parametrów jakości wody w okresie badań (1996–2001) w zależności od terminu poboru prób (O_2 w $\text{mg} \cdot \text{dm}^{-3}$, $ChZT_{Mn}$ i BZT_5 w $\text{mg} \text{O}_2 \cdot \text{dm}^{-3}$)

Water is considered to be of better quality in terms of dissolved O_2 when this indicator has higher values [Brveník 2002]. As claimed by Tölgyessy and Melichová [2000], the concentration of dissolved oxygen should not be lower than $4 \text{ mg} \cdot \text{dm}^{-3}$; the values equal to this limit or higher create suitable life conditions for water organisms, especially fish. In the case of Kadaň the latter critical value was exceeded in each year of the research period, which suggests that with respect to the oxygen regime the watercourse ensures favourable conditions for life.

With respect to sampling site, the 1996–2001 mean of O_2 concentration was lowest ($7.06 \text{ mg} \cdot \text{dm}^{-3}$) at site No 2, and highest ($7.43 \text{ mg} \cdot \text{dm}^{-3}$) at site No 11, i.e. at the mouth of the stream (Fig. 6). Its most marked increase occurred on the segments located within agricultural ecosystems (between sites No 2 and 3, and sites No 10 and 11), in both cases by ca $0.21 \text{ mg} \cdot \text{dm}^{-3}$. The effect of urban ecosystems manifested itself in lower values of the indicator downstream of the villages Štitáre, Pohranice and Golianovo (the only exception was the site located downstream of Velký Lapáš where the O_2 concentration increased).

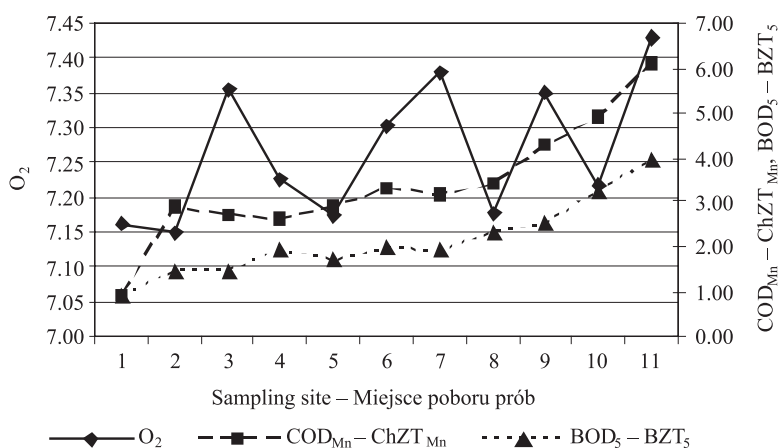


Fig. 6. Mean values of water quality parameters in study period (1996–2001) as dependent on sampling site (O₂ in mg · dm⁻³, COD_{Mn} and BOD₅ in mg O₂ · dm⁻³)

Rys. 6. Średnie wartości parametrów jakości wody w okresie badań (1996–2001) w zależności od miejsca poboru prób (O₂ w mg · dm⁻³, ChZT_{Mn} i BZT₅ w mg O₂ · dm⁻³)

Based on the calculated characteristic values of dissolved oxygen, water from all sampling sites may be classified (according to STN 75 7221 [1999]) into class III of surface water quality (polluted water; Tab. 1).

The basic statistical characteristics of the three indicators of water quality are shown in Table 2, and the results of variance analysis are provided in Table 3. It was found that the concentration of dissolved oxygen in water was highly significantly ($\alpha = 0.05$) affected by sampling time (month). The effect of sampling site was most often nonsignificant. Significant differences according to the year of research did not occur only among the years 1996 and 2000, 1996 and 2001, 2000 and 2001.

The mean BOD₅ values varied from 1.56 mg · dm⁻³ (year 2001) to 2.76 mg · dm⁻³ (year 1999), and the mean for the whole research period was 2.12 mg · dm⁻³ (Fig. 3). Similar values in surface waters were also established by other authors [Babošová et al. 1998, Kubíček et al. 1999, Mašlanka and Policht 2003].

With regard to sampling time, the 1996–2001 mean of BOD₅ values was lowest in January (1.38 mg · dm⁻³) and highest in May (2.85 mg · dm⁻³; Fig. 5). The BOD₅ decrease in winter months is probably related to the winter thermal conditions of the stream water that were unsuitable for the biological decomposition of organic matter [Sozanský et al. 2004].

The effect of sampling site on the 1996–2001 mean value of BOD₅ is shown in Figure 6. The lowest value was noted for site No 1 (origin of the watercourse) and the highest for site No 11 (mouth of the watercourse). Generally, BOD₅ was higher at the sites situated downstream of urbanised areas and lower upstream of them. This proves their role as sources of pollutants such as biodecomposable organic matter that most likely comes from untreated sewage. Urban ecosystems as a principal source of stream water pollution with biodecomposable organic matter were also mentioned by Sozanský [2004] with reference to Čerešňový potok.

Table 1. Classification of water sampled at various sites of watercourse
Tabela 1. Klasyfikacja wody pobranej w różnych miejscach ciek

Sampling site – Miejsce poboru prób														
2			3			4			5			6		
O ₂	BOD ₅ BZT ₅	COD _{Mn} ChZT _{Mn}	O ₂	BOD ₅ BZT ₅	COD _{Mn} ChZT _{Mn}	O ₂	BOD ₅ BZT ₅	COD _{Mn} ChZT _{Mn}	O ₂	BOD ₅ BZT ₅	COD _{Mn} ChZT _{Mn}	O ₂	BOD ₅ BZT ₅	COD _{Mn} ChZT _{Mn}
7.97	2.86	5.35	8.11	2.75	4.57	7.76	4.28	4.4	7.81	2.84	4.53	8.26	3.91	5.20
III	I	II	III	I	I	III	II	I	III	I	I	III	II	II
Sampling site – Miejsce poboru prób														
7			8			9			10			11		
O ₂	BOD ₅ BZT ₅	COD _{Mn} ChZT _{Mn}	O ₂	BOD ₅ BZT ₅	COD _{Mn} ChZT _{Mn}	O ₂	BOD ₅ BZT ₅	COD _{Mn} ChZT _{Mn}	O ₂	BOD ₅ BZT ₅	COD _{Mn} ChZT _{Mn}	O ₂	BOD ₅ BZT ₅	COD _{Mn} ChZT _{Mn}
7.48	3.60	4.76	7.44	5.02	5.26	6.76	4.55	6.83	6.12	6.71	9.27	7.17	7.24	9.88
III	II	I	III	III	II	III	II	II	III	III	II	III	III	II
2–11	– water-sampling sites located in longitudinal profile of watercourse Kadaň (number 1 was ascribed to the origin of the watercourse) – miejsca poboru prób wody rozmieszczone w profilu podłużnym ciek													
O ₂	– concentration of dissolved oxygen – stężenie tlenu rozpuszczonego w wodzie (mg · dm ⁻³)													
COD _{Mn}	– chemical oxygen demand determined by using potassium permanganate (mg O ₂ · dm ⁻³)													
ChZT _{Mn}	– chemiczne zapotrzebowanie tlenu określone z użyciem nadmanganianu potasu (mg O ₂ · dm ⁻³)													
BOD ₅	– 5-day biochemical oxygen demand (mg O ₂ · dm ⁻³)													
BZT ₅	– 5-dobowe biochemiczne zapotrzebowanie tlenu (mg O ₂ · dm ⁻³)													
I–III	– surface water quality classes: I – very clean, II – clean, III – polluted, IV – strongly polluted, V – very strongly polluted													
I–III	– klasy jakości wód powierzchniowych: I – bardzo czysta, II – czysta, III – zanieczyszczona, IV – silnie zanieczyszczona, V – bardzo silnie zanieczyszczona													

Table 2. Basic statistical characteristics of water quality parameters under study
Tabela 2. Podstawowe charaterystyki statystyczne badanych parametrów jakości wody

Statistical characteristics Charakterystyki statystyczne	Dissolved O ₂ Rozpuszcz. O ₂ mg · dm ⁻³	BOD ₅ BZT ₅ mg O ₂ · dm ⁻³	COD _{Mn} ChZT _{Mn} mg O ₂ · dm ⁻³
Arithmetic mean Średnia arytmetyczna	7.26	6.23	3.26
Variance – Wariacja	5.79	20.90	4.21
Standard deviation Odchylenie standardowe	2.41	4.57	2.05
Standard error Błąd standardowy	0.09	0.16	0.07
Minimum – Minimum	2.90	0.00	0.16
Maximum – Maksimum	14.50	17.62	12.26
Coefficient of variation, % Współczynnik zmienności, %	23.38	73.40	62.92

Table 3. Analysis of variance for water quality parameters under study
Tabela 3. Analiza wariancji dla badanych wskaźników jakości wody

Parameter Parametr	Source of variability Źródło zmienności	S	N	s ²	F _{cal} F _{obl}	P
Dissolved O ₂ Rozpuszcz. O ₂	location położenie	45.3628	10	4.53628	3.31	0.0004
	month miesiąc	1220.74	11	110.976	80.87	0.0000
	year rok	674.055	5	134.811	98.24	0.0000
BOD ₅ BZT ₅	location położenie	212.822	10	21.2822	13.88	0.0000
	month miesiąc	302.21	11	27.4736	17.92	0.0000
	year rok	13283.6	5	2656.73	1733.07	0.0000
COD _{Mn} ChZT _{Mn}	location położenie	1262.88	10	126.288	128.01	0.0000
	month miesiąc	292.723	11	26.6112	26.97	0.0000
	year rok	235.046	5	47.0092	47.65	0.0000

S – sum of squares – suma kwadratów

N – degrees of freedom – liczba stopni swobody

s² – variance – wariacja

F_{cal} – calculated F-value – F_{obl} – obliczona wartość F

P – confidence level – poziom ufności

A decrease in the mean BOD_5 values on segments lying between urbanised areas, within agricultural ecosystems, is indicative of self-cleaning processes running there in water.

According to the calculated characteristic values of BOD_5 (STN 75 7221 [1999]), water from the respective sampling sites can be classified into the following classes of surface water quality: sites No 2, 3 and 5 – class I (very clean water), sites No 4, 6, 7 and 9 – class II (clean water), sites No 8, 10 and 11 – class III (polluted water; Tab. 1).

The BOD_5 value was statistically significantly ($\alpha = 0.05$) influenced by sampling time (month). Sampling site produced a less significant effect. The differences according to the year of research were significant, apart from those between the years 1996 and 1997, 1996 and 1998, 1997 and 1998, 2000 and 2001.

The mean COD_{Mn} values ranged from $2.64 \text{ mg O}_2 \cdot \text{dm}^{-3}$ (year 2001) to $3.98 \text{ mg O}_2 \cdot \text{dm}^{-3}$ (year 1998). The mean calculated over the whole research period amounted to $3.32 \text{ mg O}_2 \cdot \text{dm}^{-3}$ (Fig. 4), which corresponds with the results achieved earlier in the Hostiansky stream ($3.29 \text{ mg} \cdot \text{dm}^{-3}$) [Babošová et al. 1998]. In contrast, our mean COD_{Mn} values were lower than those obtained by Skorbilowicz [2004].

The 1996–2001 mean values of COD_{Mn} were lowest for the months of December to March, with a minimum in February ($2.09 \text{ mg O}_2 \cdot \text{dm}^{-3}$), and highest from June to August, with a maximum in July ($4.22 \text{ mg O}_2 \cdot \text{dm}^{-3}$; Fig. 5). An increase in the concentration of organic substances in the summer time is most likely related to the suitable thermal conditions for the decomposition of the organic matter (plant detritus, organic matter from sewage) that gradually cumulated on the bottom of the watercourse. A similar pattern of COD_{Mn} changes with time was reported in another study [Noskovič et al. 2001].

Considering the sampling sites in the longitudinal profile of the watercourse, the biggest rise in the mean COD_{Mn} from the whole research period occurred between site No 1 (origin of the watercourse) and site No 2 (downstream of the village Štitáre, below the local pheasant breeding farm; Fig. 6). The increase amounted to ca $1.97 \text{ mg O}_2 \cdot \text{dm}^{-3}$. An increase in the 1996–2001 mean of COD_{Mn} was also found between the villages Lapáš and Golianovo. We suppose that it may be attributed to the discharge of raw sewage into the stream as the villages do not have sewage-treatment plants. The increase in the COD_{Mn} values of surface waters due to sewage discharge was reported by several authors [Pitter 1990, Hyánek et al. 1991, Noskovič et al. 2001]. Another such case was noted for sampling site No 11 (mouth of the watercourse) and site No 10, where the COD_{Mn} increase constituted $1.19 \text{ mg O}_2 \cdot \text{dm}^{-3}$. Because the segment between the two sites was densely overgrown with hydrophytes, the increased concentration of organic matter at site No 11 may have been caused by the deposition of their remains on the bottom of the stream. On these segments, the effect of agricultural ecosystems manifested itself as a decrease in the mean COD_{Mn} values, indicating that the self-cleaning processes of water took place there.

In respect of COD_{Mn} values, water from the spring usually met the criteria stipulated by the standard for drinking water (limit value $3.0 \text{ mg O}_2 \cdot \text{dm}^{-3}$), with the exception of December 1996 ($3.29 \text{ mg O}_2 \cdot \text{dm}^{-3}$) and January 1998 ($3.40 \text{ mg O}_2 \cdot \text{dm}^{-3}$).

Based on the calculated characteristic values of COD_{Mn} , water sampled from sites No 3, 4, 5 and 7 can be classified into the first class of surface water quality (very clean water), and that from all other sites, into the second class (clean water; Tab. 1).

Sampling time (month), again, had a highly significant effect ($\alpha = 0.05$) on the concentration of organic substances in water (COD_{Mn}), while the effect of sampling site

was statistically less significant. No significant differences in the mean COD_{Mn} values were found between the years 1996 and 1999, 1997 and 2000, 2000 and 2001.

CONCLUSION

In the period 1996–2001, the concentration of dissolved oxygen in the watercourse Kadaň averaged $7.26 \text{ mg} \cdot \text{dm}^{-3}$. The mean O_2 concentration was lowest in summer and autumn, most likely because of the intensive biological decomposition of organic matter, and had higher values for the sites located downstream of agricultural ecosystems than for those situated downstream of urbanised areas. The 1996–2001 mean concentration of biodegradable organic matter (BOD_5) was $2.12 \text{ mg} \cdot \text{dm}^{-3}$. The mean BOD_5 values were lowest in the months of January to March, whose thermal conditions were unsuitable for the decomposition of organic matter by microorganisms living in the watercourse, and highest in May. On average, BOD_5 reached higher values downstream of urbanised areas and tended to fall on the segments surrounded with agricultural ecosystems, which indicates that water undergoes there the process of self-cleaning. The 1996–2001 mean concentration of organic substances (COD_{Mn}) was $3.32 \text{ mg} \cdot \text{dm}^{-3}$. The mean COD_{Mn} values were lowest in December to March and highest in June to August. The COD_{Mn} changes along the longitudinal profile of Kadaň were similar to the BOD_5 pattern: on average, COD_{Mn} was higher downstream of urbanised areas, which may be attributed to the discharge of raw sewage into the watercourse. As follows from the results, various ecosystems differently influence the indicators of surface water quality.

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WPLYW EKOSYSTEMÓW ROLNYCH I OSADNICZYCH NA STĘŻENIE SUBSTANCJI ORGANICZNYCH I TLENU W WODZIE CIEKU KADAŃ

Streszczenie. Badano oddziaływanie dwóch rodzajów ekosystemów – rolnego i osadniczego, otaczających ciek, na wybrane wskaźniki jakości wody w cieku. W latach 1996–2001 co miesiąc pobierano próby wody z jedenastu przekrojów cieku Kadań i oznaczano stężenie substancji organicznych i tlenu rozpuszczonego w wodzie. Średnie w okresie badań wartości wskaźników wynosiły: $O_2 - 7,26 \text{ mg} \cdot \text{dm}^{-3}$, $BZT_5 - 2,12 \text{ mg } O_2 \cdot \text{dm}^{-3}$, $ChZT_{Mn} - 3,32 \text{ mg } O_2 \cdot \text{dm}^{-3}$. Średnie stężenie O_2 było najmniejsze latem i jesienią, co można przypisać intensywnemu rozkładowi biologicznemu materii organicznej. Wskaźnik ten przeciętnie osiągał większe wartości poniżej terenów rolnych niż poniżej miejscowości. BZT_5 średnio było najniższe od stycznia do marca, kiedy to warunki cieple cieku nie sprzyjały rozkładaniu przez mikroorganizmy materii organicznej, a najwyższe – w maju. W częściach cieku położonych poniżej miejscowości przeciętne wartości tego wskaźnika były wyższe niż na odcinkach otoczonych przez obszary rolne, co świadczy o tym, że na tych odcinkach przebiega proces samooczyszczania się wody. Średnie $ChZT_{Mn}$ było najniższe od grudnia do marca, a najwyższe – od czerwca do sierpnia. Wartości tego wskaźnika przeciętnie były większe poniżej obszarów zurbanizowanych, co należy wiązać z odprowadzaniem nieoczyszczonych ścieków do cieku Kadań. Wyniki badań wskazują, że rodzaj ekosystemu wokół cieku ma wyraźny wpływ na wskaźniki jakości wody.

Słowa kluczowe: jakość wody, rozpuszczony tlen, substancje organiczne

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