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Comparative analysis of the quality of sewage discharged from selected agglomeration sewerage systems

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Abstract

The study provides a comparative analysis of the quality of sewage discharged from selected sewerage systems. The analyzed data were collected from 10 agglomeration sewerage systems discharging sewage into collective wastewater treatment plants (WTP). The investigated pollution indicators included BOD_5, COD_{Cr}, total suspended solids and biogenic indicators such as total nitrogen and total phosphorus. These results were compared with the outcomes reported in commonly available research papers on sewage disposal. Considering the concentration of individual pollution indicators, more detailed categories of sewage pollution were adopted in this work. The sewage was divided into five basic groups: I – highly concentrated, II – concentrated, III – moderately concentrated, IV – diluted, and V – highly diluted. The sewage categories accounted for the following pollution indicators: BOD_5, COD_{Cr}, total suspended solids, total phosphorus and total nitrogen. Mean BOD_5, COD_{Cr} and total suspended solids in raw sewage were higher than average values reported in the referenced literature. Contrary to that, concentration of total phosphorus in raw sewage was significantly lower than reported by other authors. The outcomes of this study suggest that the predictions concerning pollution degree of raw sewage made at WTP design stage should not be based exclusively on general values provided in literature reports.

Key words: *agglomeration, domestic sewage, sewage composition, sewerage system*

INTRODUCTION

European Union legislation on urban wastewater treatment were set out in the Council Directive 91/271/EEC and systematized under Framework Water Directive 2000/60/EC. As per Directive 91/271/EEC, Poland acknowledged an obligation to ensure good condition of waters (flowing and standing) until the end of 2015. Directive 91/271/EEC introduced the term "agglomeration" understood as a basic area unit where urban wastewater management is conducted. Implementation of this Directive into Polish legal system required a regulation [Rozporządzenie… 2010] that governs all basic concepts contained therein. Quick development of sanitary infrastructure in Poland makes it necessary to treat the sewage so that they meet the requirements of applicable regulations [Rozporządzenie… 2014]. To achieve this goal, Poland developed the "National Programme for Municipal Wastewater Treatment" (KPOŚK) [MŚ 2003] that has been updated several times (I AKPOŚK – 7 Jun. 2005, II AKPOŚK – 2 Mar. 2010, III AKPOŚK – 1 Feb. 2011, IV AKPOŚK – 21 Apr. 2016). It enabled a construction of many new wastewater treatment

plants (WTP) and modernization of existing facilities. Composition of supplied sewage is one of the basic information required for proper design or upgrade of a wastewater treatment plant. Data on the proportions of individual pollution indicators are important for the facility operator as they may indicate possible course of biodegradation processes during the sewage treatment. According to KACZOR [2009], in the communities where no collective system for sewage discharge and disposal has been implemented, sewage composition and concentrations of individual pollutants at the stage of a new WTP design should be predicted based on the nature of agricultural production, population, presence of public buildings and small manufacturing or processing facilities such as dairies, slaughter houses or butcher's shops, and anticipated amount of sewage supplied by vacuum trucks.

The aim of the study was to compare the composition of domestic sewage entering collective wastewater treatment plants from selected agglomeration sewerage systems.

DESCRIPTION OF THE STUDY OBJECT

The study included 10 agglomeration sewerage systems: Jasło, Dębica, Sanok, Połaniec, Kolbuszowa Dolna, Trzcinnica, Kołaczyce, Haczów, Szebnie, and Przysieki. Locations of the WTPs to which the sewage was supplied via the sewerage systems are presented in Figure 1.

Basic information on the investigated sewerage systems and wastewater treatment plants are presented in Table 1.

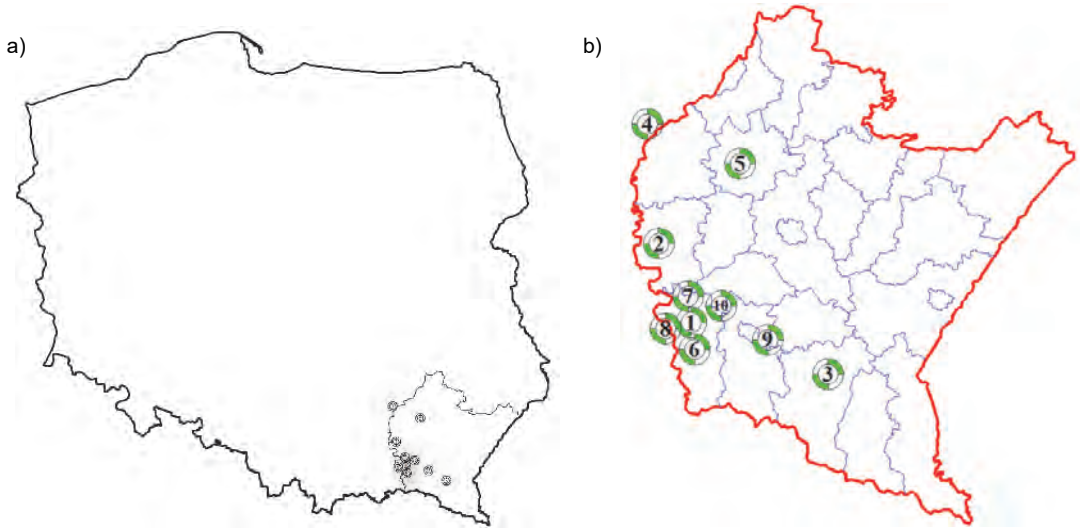

Fig. 1. Location of the investigated facilities in: a) Poland, b) Subcarpathian region (*1* – Jasło, *2* – Dębica, *3* – Trepcza, *4* – Połaniec, *5* – Kolbuszowa Dolna, *6* – Trzcinica, *7* – Kołaczyce, *8* – Przysieki, *9* – Haczów, *10* – Szebnie; source: own elaboration

Table 1. Selected parameters of the study objects

Agglomeration name	Actual population in the agglomeration, people			Length of agglomeration sewerage network, km			Amount of sewage thousands of $m^3 \cdot a^{-1}$	Design capacity of the facility $m^3 \cdot d^{-1}$
	total	number of people connected to the sewerage system	number of people served by vacuum trucks	sanitary	general	storm		
Jasło	49,141	45,064	307	350.8	34.9	16.1	5,272.0	97,000
Dębica	46,268	44,738	1,530	164.4	0	248.0	4,233.0	101,500
Trepcza	51,870	46,789	2,867	316.2	0	14.1	4,318.9	75,920
Połaniec	12,092	11,971	121	137.2	0	28.3	376.0	14,500
Kolbuszowa	13,293	11,600	1,693	73.0	10.1	10.8	410.6	18,000
Trzcinica	5,729	5,015	112	101.3	0	0	152.5	5,800
Kołaczyce	4,508	4,342	166	86.0	0	0	125.8	6,352
Przysieki	1,564	–	–	36.0	0	0	428.0	1,200
Haczów	5,768	4,674	1,094	74.4	0	0	192.5	4,500
Szebnie	2,864	2,680	120	65.1	0	0	85.0	2,900

Source: own elaboration.

MATERIALS AND METHODS

The study presents the levels of pollution indicators in raw sewage entering selected wastewater treatment plants. Raw sewage samples were collected as required by applicable standards (PN-74/C-04620/11; PN-EN 25667-2:1999). BOD_5 was evaluated as described in PN-EN 1899-1:2002 standard enti-

tled: Water quality – Determination of biochemical oxygen demand after n days (BODn) – Part 1: Dilution and seeding method with allylthiourea addition. COD_{Cr} was assessed according to PN-ISO 6060:2006 standard entitled: Water quality – Determination of chemical oxygen demand. COD was determined with the use of a photometer. Total suspended solids were determined as described in PN-EN 872:2007 standard entitled: Water quality – Determination of suspended solids by filtration through glass-fibre filters. Concentrations of total nitrogen and total phosphorus were evaluated with a photometer.

These results were compared with the outcomes reported in commonly available research papers on sewage disposal [BŁAŻEJEWSKI 2003; HEIDRICH, WITKOWSKI 2005; HEIDRICH *et al*. 2008; HENZE *et al*. 2002; ŁOMOTOWSKI, SZPINDOR 1999; TCHOBANOGLOUS *et al*. 2003].

Table 2 presents the concentrations of selected pollution indicators in raw sewage. HENZE *et al.* [2002] categorized raw sewage into four main groups: concentrated, moderately concentrated, diluted, and highly diluted.

Considering the concentration of individual pollution indicators, more detailed categories of sewage pollution were adopted in this work. Table 3 presents our categories of raw sewage depending on its pollution concentration. Ranges of individual intervals were determined based on the reports by HENZE [1982; 1992] and HENZE *et al*. [2002]. The sewage was divided into five basic groups: I – highly concentrated, II – concentrated, III – moderately concentrated, IV – diluted, and V – highly diluted. The sewage categories accounted for the following pollution indicators: BOD_5, COD_{Cr}, total suspended solids, total phosphorus and total nitrogen.

Table 2. Average concentration of selected pollution indicators in raw urban sewage

Indicator	Sewage concentration			
	concentrated	moderately concentrated	diluted	highly diluted
BOD_5, mg $O_2 \cdot dm^{-3}$	350	250	150	100
COD_{Cr}, mg $O_2 \cdot dm^{-3}$	740	530	320	210
Total suspended solids, mg·dm^{-3}	450	300	190	120
Total nitrogen, mg $N_{tot} \cdot dm^{-3}$	80	50	30	20
Total phosphorus, mg $P_{tot} \cdot dm^{-3}$	14	10	6	4

Own elaboration based on: HENZE [1982; 1992], HENZE *et al.* [2002], ODEGAARD [1992].

Table 3. Categories of raw sewage according to the concentration of investigated pollution indicators

Indicator	Raw sewage concentration categories				
	category I highly concentrated	category II concentrated	category III moderately concentrated	category IV diluted	category V highly diluted
BOD_5, mg $O_2 \cdot dm^{-3}$	$x_i \geq 450$	$450 > x_i \geq 300$	$300 > x_i \geq 200$	$200 > x_i \geq 125$	$x_i < 125$
COD_{Cr}, mg $O_2 \cdot dm^{-3}$	$x_i \geq 800$	$800 > x_i \geq 635$	$635 > x_i \geq 425$	$425 > x_i \geq 265$	$x_i < 265$
Total suspended solids, mg·dm^{-3}	$x_i \geq 500$	$500 > x_i \geq 375$	$375 > x_i \geq 245$	$245 > x_i \geq 155$	$x_i < 155$
Total nitrogen, mg $N_{tot} \cdot dm^{-3}$	$x_i \geq 90$	$90 > x_i \geq 65$	$65 > x_i \geq 40$	$40 > x_i \geq 25$	$x_i < 25$
Total phosphorus, mg $P_{tot} \cdot dm^{-3}$	$x_i \geq 16$	$16 > x_i \geq 12$	$12 > x_i \geq 8$	$8 > x_i \geq 5$	$x_i < 5$

Source: own elaboration.

RESULTS AND DISCUSSION

Figure 2 presents mean BOD_5 in the raw sewage entering the investigated facilities and shows high variability of this indicator. The highest BOD_5 was observed in the sewage collected in Kołaczyce agglomeration (mean 563.1 mg $O_2 \cdot dm^{-3}$), and the lowest in Kolbuszowa Dolna (mean 242.4 mg $O_2 \cdot dm^{-3}$). As per sewage concentration categories set out in Table 3, the sewage entering the WTP in Kołaczyce was highly concentrated (group I). The sewage entering the WTP in Kolbuszowa Dolna was moderately concentrated (group III). The remaining eight facilities were supplied with concentrated sewage (group II). A comparison of BOD_5 with the reports of other authors [HEIDRICH, WITKOWSKI 2005; HENZE *et al.* 2002; ŁOMOTOWSKI, SZPINDOR 1999] indicated higher values in this study. BŁAŻEJEWSKI [2003] claimed that BOD_5 of raw sewage was 230–500 mg $O_2 \cdot dm^{-3}$, with the mean of 300 mg $O_2 \cdot dm^{-3}$. Contrary to that, TCHOBANOGLOUS *et al*. [2003] reported mean BOD_5 to be only 190 mg $O_2 \cdot dm^{-3}$. A possible explanation is that implementation of water saving strategies resulted in increased BOD_5 in raw sewage as compared with earlier studies. A few decades or a dozen or so years ago households were charged a lump sum for tap water, and there was no motivation for its rational consumption. Therefore, due to high water consumption, collective WTPs were supplied with diluted sewage. This means the composition of raw sewage should be closely and regularly monitored and up-to-date monitoring data on pollution indocators should be used by potential WTP designers.

The data presented in Figure 3 indicated the highest mean COD_{Cr} in the raw sewage entering the WTP in Kołaczyce (1233.9 mg $O_2 \cdot dm^{-3}$). According to the categories from Table 2, the sewage entering the WTP in Kołaczyce is classified as highly concentrated (group I). This group comprised also six other agglomerations (Szebnie, Dębica, Trepcza, Przysieki, Haczów, Trzcinica), where mean COD_{Cr} of raw sewage ranged from 848.5 mg $O_2 \cdot dm^{-3}$ to 1059.7 mg $O_2 \cdot dm^{-3}$. The lowest COD_{Cr} was reported in Kolbu-

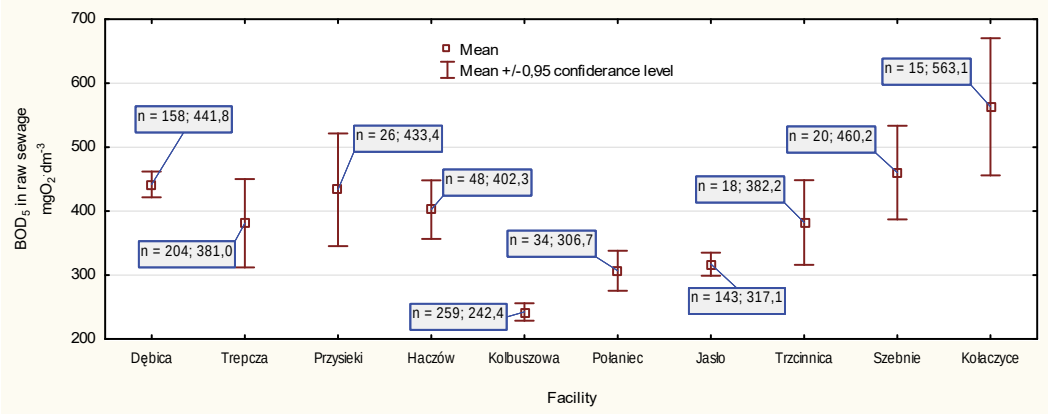

Fig. 2. Mean BOD_5 in raw sewage entering the investigated facilities; source: own study

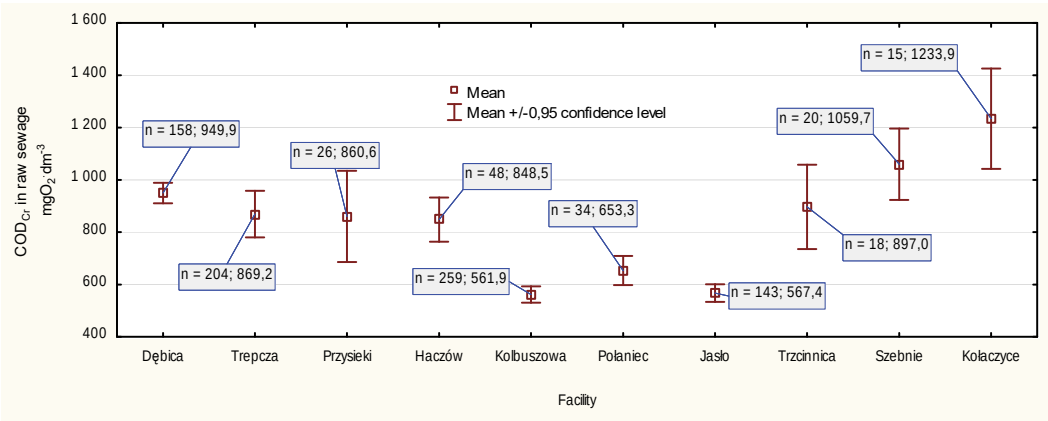

Fig. 3. Mean COD_{Cr} in raw sewage entering the investigated facilities; source: own study

szowa agglomeration, where its mean value was 561.9 mg $O_2 \cdot dm^{-3}$ (group III – concentrated sewage). The above data showed high COD_{Cr} for the majority of the investigated facilities. This might be an effect of a systematic decrease in tap water consumption. A decrease in water consumption is due to economic reasons (increasing cost of water supply and sewage disposal), and the use of water-saving sanitary devices in individual households. Large differences between mean values might be due to infiltration or incidental waters that may enter the sewerage network and dilute the sewage MŁYŃSKI *et al.* [2016]. On the other hand, the sewage supplied with vacuum tanks increases general sewage concentration. HENZE *et al.* [2002] claimed that COD_{Cr} usually ranged between 210 and 740 mg $O_2 \cdot dm^{-3}$, with a mean of 530 mg $O_2 \cdot dm^{-3}$. However, TCHOBANOGLOUS *et al.* [2003] reported mean COD_{Cr} to be 430 mg $O_2 \cdot dm^{-3}$. Much higher COD_{Cr} was reported by BŁAŻEJEWSKI [2003], who determined mean COD_{Cr} of raw sewage to be 700 mg $O_2 \cdot dm^{-3}$. High variability of this parameter in Małopolska region was described by KACZOR [2009], as it ranged from 109 to 1669 mg $O_2 \cdot dm^{-3}$, with the mean of 700 mg $O_2 \cdot dm^{-3}$. Summing up, the results of this study were the most similar to those obtained by BŁAŻEJEWSKI [2003] and KACZOR [2009].

Figure 4 presents mean results for total suspended solids in raw sewage entering the investigated facilities. Similarly as for both oxygen-related indicators, significant differences in mean values of the analyzed indicators in the sewage entering the investigated facilities are visible. Very high concentrations of suspended solids were observed in the sewage supplied to the WTP in Kołaczyce (mean 965 mg·dm^{-3}). The sewage was highly concentrated and was classified as the first group (highly concentrated). The first group comprises sewage in which total suspended solids exceeds 500 mg·dm^{-3}, and that means the values observed in Kołaczyce were very high. Mean total suspended solids in raw sewage exceeding 500 mg·dm^{-3} was also reported in two other facilities (Przysieki and Szebnie). Based on mean values of this indicator, the sewage entering the WTPs in Dębica, Trepcza and Trzcinica were classified into the second group (concentrated sewage). The sewage entering the facilities in Haczów and Kolbuszowa were classified into the third group. The lowest concentrations of total suspended solids were observed in the sewage entering the facilities in Jasło and Połaniec, and they were classified into the group of diluted sewage (IV). What deserves attention is that there are very large differences between the maximum and minimum concentrations of total suspended solids in sewage flowing into the treatment plants in Przysieki and Kołaczyce. It might be suggested that this situation results from the periodic inflow of rainwater to the discussed

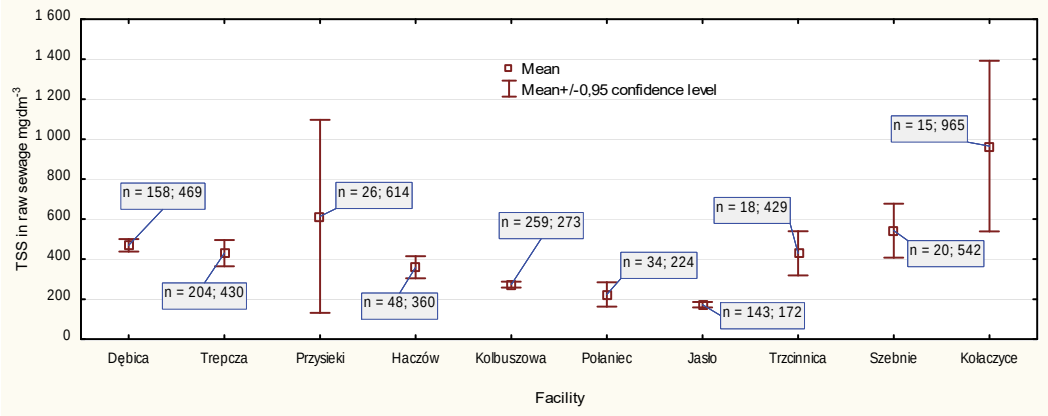

Fig. 4. Mean total suspended solids (TSS) in raw sewage entering the investigated facilities; source: own study

sewerage systems, which caused extremely low values of the concentrations of total suspended solids. On the other hand, extremely high values may result from discharge of liquid waste by gully emptiers.

According to BŁAŻEJEWSKI [2003], mean concentration of total suspended solids in raw sewage was 310 mg·dm^{-3}. However, HENZE *et al.* [2002] and HEIDRICH and WITKOWSKI [2005] claimed mean value of this parameter to be 400 mg·dm^{-3}.

The study determined also the level of biogenic indicators in the raw sewage entering the investigated facilities. Resulting data are presented for only five selected facilities (Fig. 5), as there were no sufficient data for the others. The outcomes depicted in Figure 5 indicate moderate concentration of total nitrogen in the raw sewage. The highest mean concentrations were noticed for Dębica and Połaniec, and they were 85.2 and 82.7 mg N_{tot}·dm^{-3}, respectively. The remaining three facilities were supplied with moderately concentrated sewage (group III). HENZE *et al.* [2002], TCHOBANOGLOUS *et al.* [2003] and BŁAŻEJEWSKI [2003] reported mean concentration of total nitrogen in raw sewage to be around 50 mg N_{tot}·dm^{-3}. The results most similar to those presented in this study were obtained by KACZOR [2009], who evaluated multiple facilities in the Małopolska region and found mean concentration of total nitrogen to be 74 mg N_{tot}·dm^{-3}.

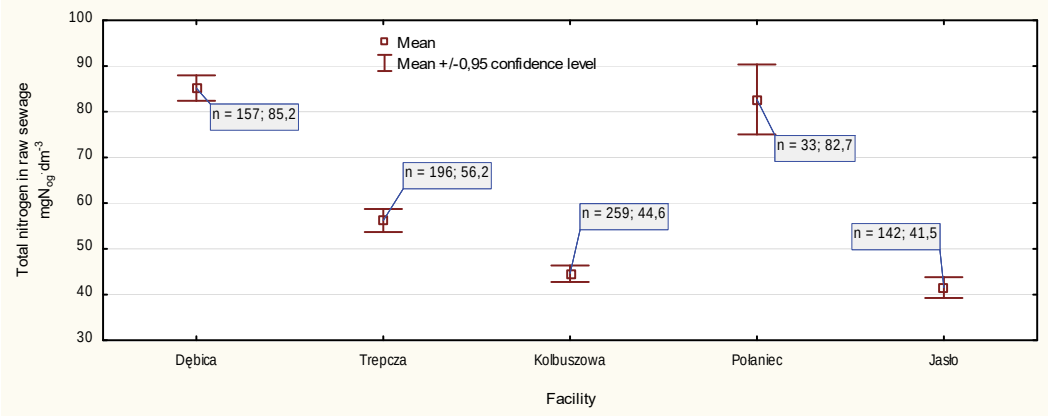

Fig. 5. Mean total nitrogen content in raw sewage entering the investigated facilities; source: own study

Concentrations of total phosphorus incoming to the selected facilities are presented in Figure 6. The data shown in this figure demonstrate that in terms of total phosphorus the incoming sewage was moderately concentrated (Dębica, Trepcza, Połaniec) or diluted (Kolbuszowa and Jasło). Other researchers i.e. ŁOMOTOWSKI and SZPINDOR [1999] and HENZE *et al.* [2002] reported significantly higher concentrations of total phosphorus in raw sewage (mean 16 mg P_{tot}·dm^{-3}). Contrary to that, KACZOR [2009] claimed that mean concentration of total phosphorus was around 11 mg P_{tot}·dm^{-3}, and this was closer to the values presented in Figure 6.

Concentration of pollution indicators is closely related to the efficiency of biological decomposition of the sewage. Figure 7 presents mean COD_{Cr}:BOD_5 ratio for the raw sewage entering the investigated facilities. Data displayed in Figure 7 demonstrate that in most of the facilities COD:BOD_5 ratio in the raw sewage was above 2.2, i.e. the maximum value required for effective treatment of carbon compounds. COD:BOD_5 ratio conducive to biological treatment of raw sewage was detected only in the WTP in Jasło. The highest mean value of COD:BOD_5 ratio was as high as 2.7 and was calculated for Trepcza. The greatest range of values of COD:BOD_5 ratio was observed

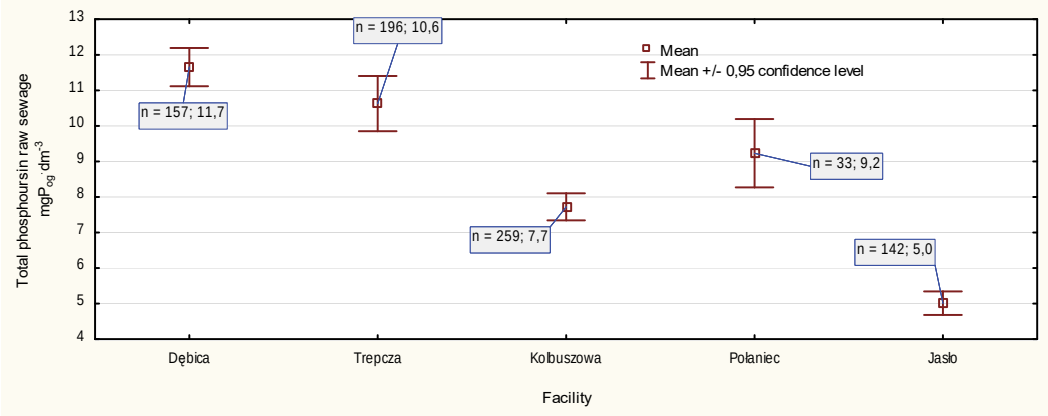

Fig. 6. Mean total phosphorus content in raw sewage entering the investigated facilities; source: own study

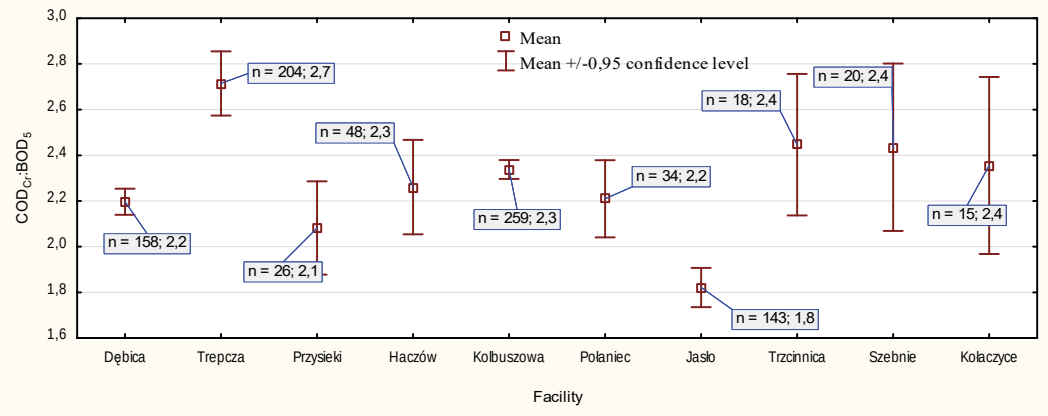

Fig. 7. Mean COD:BOD$_5$ ratios for raw sewage entering the investigated facilities; source: own study

for sewage flowing into the treatment plants in Trzcinnica, Szebna and Kołaczyce. This may result from inflow of wastewater of different origin than household, e.g. from the local industry. KACZOR [2009] claimed that mean COD:BOD$_5$ ratio was around 2.23.

Figure 8 presents mean BOD$_5$:N$_{tot}$ ratio for the raw sewage entering the investigated facilities. This ratio demonstrates potential effectiveness of biological methods of nitrogen removal. Analysis of the data presented in Figure 7 indicates that the highest BOD$_5$:N$_{tot}$ ratio was observed for the sewage entering the WTP in Jasło (7.8). This ratio was significantly lower (mean 3.8) for the sewage supplied to the WTP in Połaniec. In the other facilities, this parameter was above 5. Nitrogen can be properly removed when BOD$_5$:N$_{tot}$ ratio is higher than 4, and this requirement was met in nearly all facilities. Mean BOD$_5$:N$_{tot}$ ratio in raw sewage entering multiple facilities in the Małopolska region reported by KACZOR [2009] was 4.43.

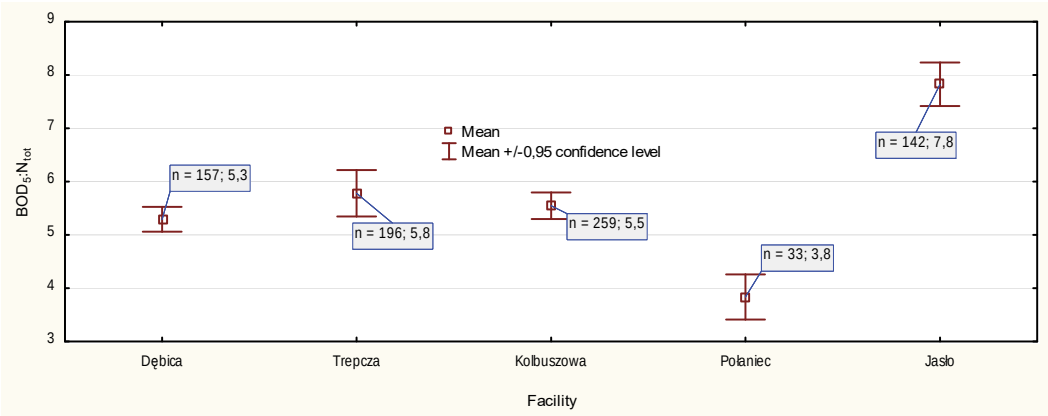

Fig. 8. Mean BOD$_5$:N$_{tot}$ ratio for raw sewage entering the investigated facilities; source: own study

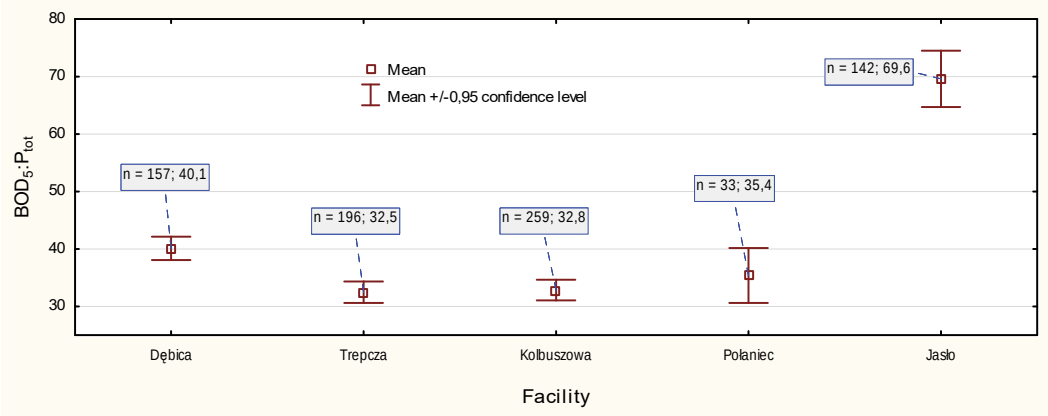

Fig. 9. Mean BOD_5:P_{tot} ratio for raw sewage entering the investigated facilities; source: own study

Data showed in Figure 9 indicate substantial differences between mean BOD_5:P_{tot} ratios. Moreover, mean BOD_5:P_{tot} ratio for all the facilities was significantly higher than required (>25) for effective removal of total phosphorus. KACZOR [2009] claimed that mean BOD_5:P_{tot} ratio for the wastewater treatment plants in the Małopolska region was much higher and amounted to 28.9. Low values of BOD_5:P_{tot} ratio may encourage potential designers of a WTP to implement an additional step of chemical precipitation of phosphorus to improve the effectiveness of its removal.

CONCLUSIONS

1. Mean BOD_5, COD_{Cr} and total suspended solids in the raw sewage were higher than mean values reported in the referenced literature. However, concentration of total phosphorus in the raw sewage was significantly lower than described by other authors.

2. The study outcomes suggest that implementation of water saving strategies might have resulted in increased BOD_5 in raw sewage as compared with earlier studies. A few decades or a dozen or so years ago households were charged a lump sum for tap water, and there was no motivation for its rational consumption. Therefore, due to high water consumption, collective WTPs were supplied with diluted sewage. Close and regular monitoring of the composition of raw sewage is recommended and up-to-date monitoring data on pollution indicators should be used by potential WTP designers.

3. The relationships between mean ratios of pollution indicators COD:BOD_5 and BOD_5:N_{tot} indicated that the sewage discharged from the investigated agglomeration sewerage systems may be effectively subjected to advanced biological treatment involving removal of nitrogen compounds.

4. Mean BOD_5:P_{tot} ratio for all the facilities was significantly higher than required (>25) for effective removal of total phosphorus. The observed high ratios of BOD_5:P_{tot} indicate the susceptibility of sewage to biological phosphorus removal.

5. The outcomes of this study suggest that the predictions concerning pollution degree of raw sewage made at WTP design stage should not be based exclusively on general values provided in literature reports.

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Rozporządzenie Ministra Środowiska z dnia 1 lipca 2010 r. w sprawie sposobu wyznaczania obszaru i granic aglomeracji [Regulation of the Minister of the Environment of 1 July 2010 on the definition of the area and boundaries of an agglomeration]. Dz.U. 2010. Nr 137 poz. 922.

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Analiza porównawcza jakości ścieków odpływających z wybranych aglomeracji kanalizacyjnych

STRESZCZENIE

W pracy przedstawiono analizę porównawczą jakości ścieków odpływających wybranymi systemami kanalizacyjnymi. Badania przeprowadzono w dziesięciu wybranych aglomeracjach kanalizacyjnych odprowadzających ścieki do oczyszczalni zbiorczych. Analizie poddano podstawowe wskaźniki zanieczyszczenia ścieków (BZT5, ChZTCr, zawiesina ogólna) oraz biogenne (azot ogólny i fosfor ogólny). Porównano średnie wartości poszczególnych wskaźników zanieczyszczenia ścieków odpływających z wybranych aglomeracji kanalizacyjnych. Uzyskane wyniki porównano z wartościami zestawionymi w ogólnodostępnej literaturze związanej z tematyką unieszkodliwiania ścieków. Do badań przyjęto podział ścieków ze względu na koncentrację poszczególnych wskaźników zanieczyszczenia. Ścieki podzielono na pięć zasadniczych grup (I – ścieki bardzo stężone, II – ścieki stężone, III – ścieki średnio stężone, IV – ścieki rozcieńczone, V – ścieki bardzo rozcieńczone). Uzyskane średnie wartości BZT5, ChZTCr i zawiesiny ogólnej w ściekach surowych były większe od wartości średnich przedstawianych w analizowanej literaturze. Natomiast stężenie fosforu ogólnego w ściekach surowych było zdecydowanie mniejsze niż podają inni autorzy. Wyniki przeprowadzonych badań wskazują, że podczas projektowania oczyszczalni ścieków należy zachować pewną ostrożność w prognozowaniu stężeń zanieczyszczeń w ściekach surowych wyłącznie na podstawie uogólnionych wartości podawanych w literaturze.

Słowa kluczowe: *aglomeracja, skład ścieków, system kanalizacyjny, ścieki bytowe*