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ANALYSIS OF BIOGENIC MATTER BALANCE IN MUNICIPAL WASTEWATER IN JAWORZNO-DAB WWTP

ANALIZA BILANSU ZWIĄZKÓW BIOGENNYCH W ŚCIEKACH KOMUNALNYCH OCZYSZCZANI JAWORZNO-DĄB

Abstract: The role of municipal wastewater in the development of eutrophication processes due to high content of nutrients will be increasing correspondingly with economic development. However, treatment technologies do not always provide an effective protection of surface waters against eutrophication. Biogenic substances on their way from the place of their origin to the discharge to water receiver undergo significant transformations. The knowledge about it is essential to understand some theoretical issues and to develop the methods of protection against eutrophication. In recent decades, many countries have introduced an advanced wastewater treatment technologies for increased nutrients removal. However, regardless of the fact that load of biogenic substances was significantly reduced, the substantial successes in preventing of eutrophication processes has failed to achieve. Moreover, as research has shown, wastewater treated in conventional biological technologies can accelerate the process of eutrophication, because it characterized by a high content of mineral forms of nitrogen and phosphorus, which are easily absorbed by aquatic vegetation. European and national requirements in terms of treated wastewater quality discharged into receivers concern the contents of total nitrogen and phosphorus, while the most available to algae are their dissolved inorganic forms. Knowledge about the content of bioavailable forms of nutrients in wastewater discharged into receiver allows to make rational decisions when choosing wastewater treatment technologies, as advanced technologies of deep nutrients removal are an extremely capital-intensive investments. In view of the above considerations the research was undertaken on the content of various forms of nitrogen and phosphorus in municipal wastewater discharged from wastewater treatment plant Jaworzno-Dab, the results of which are presented in this article.

Keywords: eutrophication, municipal wastewater, biogenic matter, bioavailability of nutrients

Introduction

The assessment of influence of various wastewater types on eutrophication development in surface waters allows to conclude that municipal wastewaters have prevailing role in surface water pollution. From 50 to 90% of phosphorus compounds are delivered in that way to water receivers from which 7 to 20% represents phosphorus contented in detergents. On the other hand, detergents of older generation in 50% are composed of phosphorus [1, 2]. The role of wastewater in the acceleration of eutrophication process will increase with the economic development, still wastewater treatment technologies cannot always provide the proper protection against eutrophication.

Removing biogenic substances from wastewater become an up-to-date problem when it appeared, that conventional treatment technologies are not effective enough in the matter of nitrogen and phosphorus elimination. In the past decades in many countries the advanced technologies of wastewater treatment were implemented in order to achieve the increased removal of nutrients. However, regardless of the fact that the load of biogenic substances was significantly reduced, the substantial successes in preventing of eutrophication processes has failed to achieve. Moreover, as some researchers have shown, wastewater

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treated in conventional biological technologies can accelerate the process of eutrophication, because it is characterized by high content of mineral forms of nitrogen and phosphorus, which are easily absorbed by aquatic vegetation [3, 4]. European and national requirements in terms of treated wastewater quality discharged into receivers concern the contents of total nitrogen and phosphorus [5]. Various number of publications on eutrophication process development shows, that just dissolved inorganic forms of nitrogen and phosphorus are the most available to algae [6-9]. Different algae species have specific demands concerning bioavailable forms of nitrogen and phosphorus. For example, orthophosphate $P\text{-}PO_4$ is concerned to be the most assimilable form of phosphorus compounds for phytoplankton. Its content depends on water pH value. When pH value amounts 3-7 dihydrogen phosphate anion H_2PO_4 dominates, when pH = 8-12 hydrophosphate ion HPO_4 prevails. The most bioavailable nitrogen form is nitrate nitrogen which can be consumed, for example, by *Cyanobacteria* representatives like: *Anabaena variabilis*, *Nostoc paludosum* and *Nostoc coeruleum*. Such species as *Microcystis aeruginosa*, *Calothrix elenkini*, *Hapalosiphon fomtinalis* etc. reproduce better consuming the ammonia nitrogen [10]. The majority of green algae absorbs most actively the nitrate nitrogen. Some species of higher aquatic vegetation, for example the reed, also absorb better the ammonium nitrogen. The least assimilable form of mineral nitrogen is nitrite nitrogen.

The specificity of mineral nutrition of aquatic vegetation is not fully investigated due to the high degree of complexity of the studies, that require the interdisciplinary team of specialists involvement.

Knowledge about the content of bioavailable forms of nutrients in wastewater discharged into receiver allows to make rational decisions when choosing wastewater treatment technologies, as advanced technologies of deep nutrients removal are extremely capital-intensive investments.

In view of the above considerations the research was undertaken on the content of various forms of nitrogen and phosphorus in municipal wastewater discharged from wastewater treatment plant Jaworzno-Dab, the results of which are presented in this article.

Materials and methods

Municipal wastewater treatment plant (WWTP) Jaworzno-Dab is located between two cities Jaworzno and Chelmek in the eastern part of Silesia Region of Poland. Untreated wastewater is transported to wastewater treatment plant by two canals. There are also sanitary sewage being transported by septic tankers from the areas without access to municipal sewage system. The maximum wastewater flow rate is around 25,000 m^3 per day and the maximum load according to operative water permit equals the population equivalent PE = 87,500. Due to the modernization of sewage system the forecasting load is going to rise up to 125,000 PE [11]. Treated wastewater is discharged to the river Przemsza in the point located at km 9+518.

Jaworzno-Dab WWTP operation is based on low-loaded activated sludge technology with advanced nutrients removal and possible phosphorus chemical precipitation. The currently valid water permit [11] obligates to achieve the following parameters in discharge from the WWTP: BOD - 15 mg O_2/dm^3, COD - 125 mg O_2/dm^3, TSS - 35 mg/dm^3, total

nitrogen - 15 mg N/dm^3, total phosphorus - 2 mg P/dm^3. The technological scheme of the WWTP is shown in Figure 1.

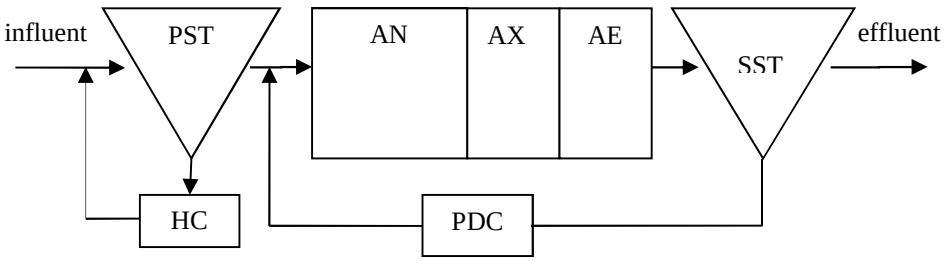

Fig. 1. Technological scheme of Jaworzno-Dab WWTP (PST - primary settling tank, HC - hydrolysis chamber, AN - anaerobic chamber, AX - anoxic chamber, AE - aerobic chamber, SST - secondary settling tank, PDC - recirculated sludge pre-denitrification chamber)

Table 1

Concentration of different forms of nitrogen and phosphorus in raw wastewater

Year	$N\text{-}NH_4$ [mg/dm^3]	$N\text{-}NO_2$ [mg/dm^3]	$N\text{-}NO_3$ [mg/dm^3]	N Kj [mg/dm^3]	TN [mg/dm^3]	N_{org} [mg/dm^3]	TP [mg/dm^3]	$P\text{-}PO_4$ [mg/dm^3]
2013	41.40	0.00	0.31	64.49	64.80	23.10	8.48	6.49
2014*	43.08	0.00	0.30	71.19	71.49	24.64	11.48	8.40
2014**	41.50	0.00	0.27	69.86	70.13	21.55	10.24	7.58

*results for months I-VI with primary settling tank ON. ** results for months VII-XII with primary settling tank OFF.

Table 2

Concentration of different forms of nitrogen and phosphorus in wastewater after mechanical treatment

Year	$N\text{-}NH_4$ [mg/dm^3]	$N\text{-}NO_2$ [mg/dm^3]	$N\text{-}NO_3$ [mg/dm^3]	N Kj [mg/dm^3]	TN [mg/dm^3]	N_{org} [mg/dm^3]	TP [mg/dm^3]	$P\text{-}PO_4$ [mg/dm^3]
2013	41.40	0.00	0.33	65.83	66.16	24.44	8.69	6.98
2014*	44.00	0.00	0.81	68.36	69.17	24.36	11.87	9.58
2014**	n.e.	n.e.	n.e.	n.e.	n.e.	n.e.	n.e.	n.e.

n.e. - not examined

Table 3

Concentration of different forms of nitrogen and phosphorus in wastewater after biological treatment

Year	$N\text{-}NH_4$ [mg/dm^3]	$N\text{-}NO_2$ [mg/dm^3]	$N\text{-}NO_3$ [mg/dm^3]	N Kj [mg/dm^3]	TN [mg/dm^3]	N_{org} [mg/dm^3]	TP [mg/dm^3]	$P\text{-}PO_4$ [mg/dm^3]
2013	0.30	0.00	7.87	1.63	9.50	1.33	0.70	0.55
2014*	0.49	0.00	8.29	1.81	10.10	1.32	0.35	0.23
2014**	2.00	0.00	7.07	2.85	9.92	0.85	0.73	0.57

Data used for analysis were obtained from the results of wastewater quality monitoring conducted by WWTP laboratory. The values of examined parameters were systematized, organized and prepared for analysis. Basis was constituted from the average annual values of concentrations, of different forms of nutrients within the period of 2013 and 2014. The analysis concerned the quality of raw wastewater, wastewater after mechanical treatment and after biological treatment. Due to the need of primary settling tank modernization it was turned off the operation in June 2014. Owing to this the parameters relating to the

examined period between July-December 2014 were analyzed separately. The results of analysis on the content of different forms of biogenic substances in wastewater after different steps of treatment are shown in Tables 1-3.

After analyzing the data shown in Table 3 it can be stated, that exclusion of primary settling tank did not affect seriously on the increase of neither total nitrogen nor total phosphorus. However it brought to the changes in the structure of content of different forms of nitrogen compounds, which is especially distinct for the concentration of ammonia nitrogen and Kjeldahl nitrogen.

Taking into account, that the main objective of research is the content of mineral forms of nitrogen and phosphorus in treated wastewater, which are immediately bioavailable for water vegetation, the next step was to assess the content structure of particular bioavailable nutrient forms of biogenic compounds.

Results and discussion

Content structure of nitrogen compounds in wastewater

One of the main component of raw wastewater in Jaworzno-Dab WWTP is ammonia nitrogen (64%) and organic nitrogen (35%). It suggests that the ammonification processes had already started in sewage network. Technological system of wastewater treatment plant provides the stabile effect of total nitrogen removal, so WWTP meets the requirements of existing Regulation [12]. The average level of total nitrogen removal is about 86% and its maximum concentration in the effluent not exceeds 10 mg/dm^3.

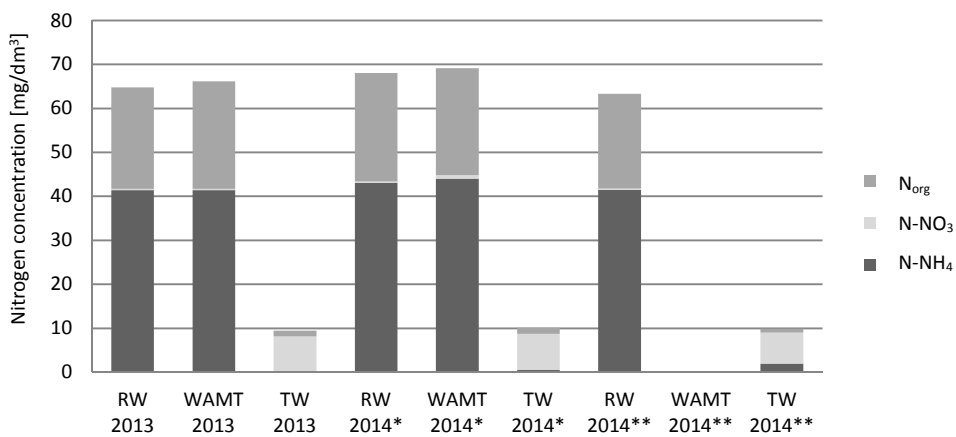

Fig. 2. Nitrogen compounds in wastewater after particular treatment stages (RW - raw wastewater, WAMT - wastewater after mechanical treatment, TW - biologically treated wastewater), * results for months I-VI with primary settling tank ON, ** results for months VII-XII with primary settling tank OFF

The percentage content of particular nitrogen compounds (N-NH_4; N-NO_3; N_{org}) in wastewater discharged to Przemsza river in 2013 is presented as follows: 3.18; 82.86; 13.95% respectively. In the first half of 2014 any severe changes were not observed and the

content structure of these compounds were the following: 4.86; 82.10; 13.04. However in the second half of 2014, when the primary settling tank was turned off, the concentration of ammonia nitrogen increased and content structure of different nitrogen forms mentioned above changed as following: 20.21; 71.23; 8.56% respectively. It can be assumed that turning off the primary settling tank caused serious changes in the structure of nitrogen compounds in effluent from WWTP.

The results of analysis of wastewater quality after mechanical treatment had shown the slight increase of organic nitrogen amount, which can be an effect of a number of difficulties connected with primary settling tank exploitation. Figure 2 presents the content of nitrogen compounds in wastewater after particular treatment stages.

Content structure of phosphorus compounds in wastewater

Phosphorus in raw wastewater is generally represented by phosphates (74.59%) and organic phosphorus (25.41%). Wastewater after biological treatment consists mainly of orthophosphates PO_4 (79.07%) and organic phosphorus (20.93%). In the first half of 2014 the phosphates amount was around 66.65% and organic phosphorus - about 33.35%. After turning off the primary settling tank in June 2014 the concentration of phosphates increased to 78.66% and the concentration of organic phosphorus accordingly dropped to 21.34% (Fig. 3). Wastewater treatment technology provides the average reduction of total phosphorus up to 94% (against required min. 80%) and its maximum concentration is 0.7 mg/dm^3 which means that WWTP Jaworzno-Dab meets the requirements of current Regulation [12] in case of total phosphorus reduction.

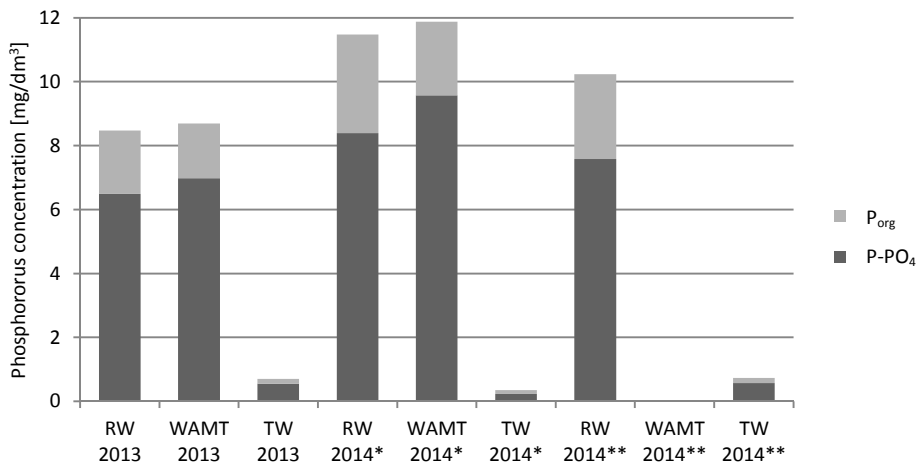

Fig. 3. Phosphorus compounds in wastewater after particular treatment stages (RW - raw wastewater, WAMT - wastewater after mechanical treatment, TW - biologically treated wastewater), * results for months I-VI with primary settling tank ON, ** results for months VII-XII with primary settling tank OFF

Amounts of immediately bioavailable nitrogen and phosphorus compounds

Results of analysis of concentrations of organic and mineral forms of nitrogen and phosphorus are presented in Tables 4 and 5. These results are relating to the period with primary settling tank operating and turned off.

Table 4

Nitrogen compounds in raw and treated wastewater

Nitrogen	TN [mg N/dm^3]	N_{org} [mg N/dm^3]	$N_{min.}$ [mg N/dm^3]	N_{org} / $N_{min.}$ [%]	Bioavailable N [%]	NO_3 / $N_{min.}$ [%]	NH_4 / $N_{min.}$ [%]
Raw wastewater							
2013	64.80	23.10	41.71	55.38	64.36	0.74	99.26
2014*	71.49	24.64	43.38	56.79	60.69	0.69	99.31
2014**	70.13	21.55	41.77	51.60	59.56	0.64	99.36
Biologically treated wastewater							
2013	9.50	1.33	8.18	16.21	86.05	96.30	3.70
2014*	10.10	1.32	8.78	14.99	86.96	94.41	5.59
2014**	9.92	0.85	9.07	9.36	91.44	77.90	22.10

* results for months I-VI with primary settling tank ON. ** results for months VII-XII with primary settling tank OFF

Table 5

Phosphorus compounds in raw and treated wastewater

Phosphorus	TP [mg/dm^3]	P_{org} [mg P/dm^3]	$P_{min.}$ [mg P/dm^3]	P_{org} / $P_{min.}$ [%]	Bioavailable P [%]
Raw wastewater					
2013	8.48	1.98	6.49	30.52	76.62
2014*	11.48	3.08	8.40	36.72	73.14
2014**	10.24	2.66	7.58	35.12	74.01
Biologically treated wastewater					
2013	0.70	0.15	0.55	26.47	79.07
2014*	0.35	0.12	0.23	50.03	66.65
2014**	0.73	0.16	0.57	27.13	78.66

* results for months I-VI with primary settling tank ON. ** results for months VII-XII with primary settling tank OFF

The analysis of data presented in Tables 4 and 5 allows to sum up, that the ratio between organic nitrogen and mineral nitrogen in treated wastewater decreased about 1.8 times during the period with operating primary settling tank and 5.5 times when it was turned off. The content of bioavailable nitrogen compounds increased 1.4 times with operating primary settling tank and 1.5 time when it was turned off. The dominating bioavailable nitrogen form in biologically treated wastewater is nitrate nitrogen, contrary to raw wastewater, where the main bioavailable form of nitrogen is ammonia nitrogen. It should also be noted, that turning off the secondary settling tank has led to the reduction of nitrite nitrogen share by 12.8% and corresponding increase of ammonia nitrogen share by 17.5% in treated wastewater.

The ratio of organic phosphorus and mineral phosphorus in raw wastewater has averaged 34.0%, while in treated wastewater in 2013 and under the settling tank turned off

in 2014 it decreased slightly and accounted for an average of 26.8%. There was one exception before June 2014 when this ratio increased by 13%.

Amount of bioavailable phosphorus compounds in biologically treated wastewater increased by 3.6%, but in the first part of 2014 the share of mineral phosphorus was lower due to different content of phosphorus forms in raw wastewater. The results are presented in Figures 4 and 5.

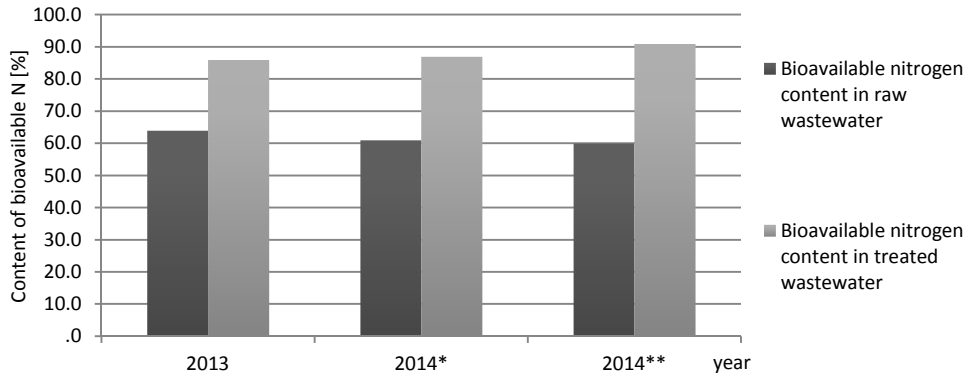

Fig. 4. Content of bioavailable nitrogen forms (sum of NO_3, NO_2 and NH_4) in raw and treated wastewater; * results with primary settling tank ON, ** results with primary settling tank OFF

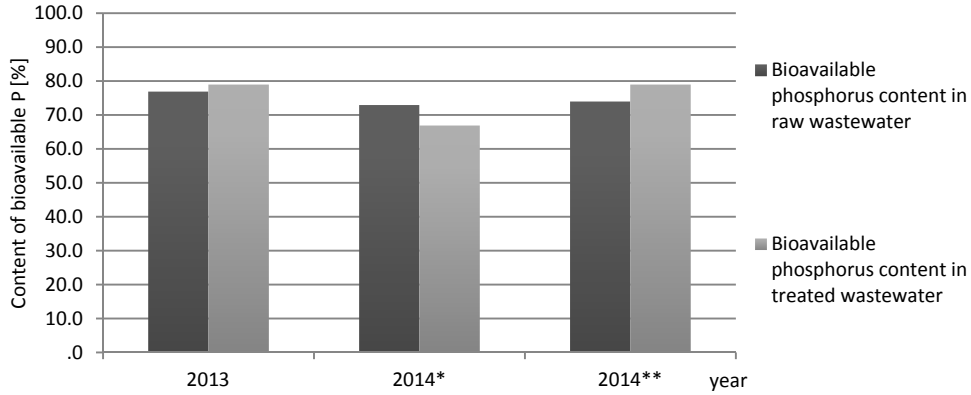

Fig. 5. Content of bioavailable phosphorus forms (PO_4) forms in raw and treated wastewater; * results with primary settling tank ON, ** results with primary settling tank OFF

Conclusions

The analysis of the state of knowledge on treated municipal wastewater impact on trophic status of receiving surface waters and analysis of wastewater quality treated in low-loaded activated sludge technology with advanced nutrients removal in Jaworzno-Dab WWTP allowed to draw the following conclusions:

- Eutrophication manifested by intensive development of aquatic vegetation is accelerated mainly by excessive amounts of mineral forms of nitrogen and phosphorus introducing into receivers together with biologically treated wastewater.
- Biologically treated wastewater, meeting the legislative requirements concerning total nitrogen and total phosphorus content, are enriched in mineral forms of these biogenic elements immediately bioavailable for aquatic vegetation.
- The above mentioned statement was confirmed by the analysis of raw and treated wastewater content from Jaworzno-Dab WWTP.
- The content of bioavailable forms of nitrogen and phosphorus in biologically treated wastewater from WWTP Jaworzno-Dab has increased correspondingly by 22% and 3.6%. This fact shows the growth of biologically treated wastewater potential for intensification of surface water eutrophication.

Further research in undertaken direction would allow the optimization of decision-making process in the sphere of wastewater treatment technologies taking into consideration the eutrophication processes mechanisms.

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ANALIZA BILANSU ZWIĄZKÓW BIOGENNYCH W ŚCIEKACH KOMUNALNYCH OCZYSZCZANI JAWORZNO-DĄB

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Abstrakt: Rola ścieków komunalnych w rozwoju procesów eutrofizacji ze względu na dużą zawartość substancji biogennych będzie wzrastać wraz z rozwojem gospodarczym, a technologie ich oczyszczania nie zawsze zapewniają skuteczną ochronę wód przed eutrofizacją. Substancje eutrofizujące na drodze od miejsca ich powstawania do miejsca zrzutu do odbiornika ulegają znacznym transformacjom, których znajomość jest bardzo istotna do zrozumienia niektórych zagadnień teoretycznych oraz opracowania sposobów ochrony przed eutrofizacją. W ostatnich dziesięcioleciach w wielu państwach wprowadzono zaawansowane technologie oczyszczania ścieków w celu wzmożonego usuwania substancji biogennych. Jednak bez względu na to, że ładunki substancji eutrofizujących znacznie się zmniejszyły, nie udało się osiągnąć znacznych sukcesów w zapobieganiu procesom eutrofizacji. Co więcej, jak pokazały badania, ścieki oczyszczone w konwencjonalnych układach biologicznego oczyszczania przyspieszają procesy eutrofizacji, ponieważ zawierają duże ilości mineralnych form azotu i fosforu, łatwo przyswajalnych przez roślinność wodną. Wymagania europejskie i krajowe w zakresie jakości ścieków oczyszczonych wprowadzanych do odbiorników dotyczą zawartości ogólnego azotu i fosforu, natomiast najbardziej dostępną dla glonów formą tych pierwiastków są ich rozpuszczone nieorganiczne formy. Wiedza o zawartości przyswajalnych form związków biogennych w ściekach, odprowadzanych do wód powierzchniowych, pozwoli na podejmowanie racjonalnych decyzji przy wyborze technologii oczyszczania ścieków, ponieważ zaawansowane technologie głębokiego usuwania substancji biogennych stanowią wyjątkowo kapitałochłonne inwestycje. Mając na uwadze powyższe rozważania, podjęto badania nad strukturą zawartości różnych form azotu i fosforu w ściekach komunalnych odprowadzanych z oczyszczalni ścieków Jaworzno-Dąb, wyniki których przedstawiono w niniejszym artykule.

Słowa kluczowe: eutrofizacja, ścieki komunalne, substancje biogenne, bioprzyswajalność