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ASSESSMENT OF THE EFFECTS OF MODERNIZATION OF MUNICIPAL WASTEWATER TREATMENT PLANTS IN RAWICZ AND KOŚCIAN

The increase in the standard of living and economic development of cities and smaller settlement units implies the extension and modernization of infrastructure, including wastewater collection and treatment systems, which is closely related to the protection of surface water and groundwater. This study analyzes the effects of the modernization of two wastewater treatment plants carried out between 2019 and 2020. These are the municipal wastewater treatment plants for Rawicz and Kościan in the Wielkopolska region. The analysis of contamination indicators and wastewater treatment efficiency showed that in both plants, the modernization and extension of wastewater treatment and sludge treatment technologies resulted in improved treated wastewater parameters and better sludge preparation for use. The high efficiency of contaminant removal (mostly above 94%) improves the standard of living, intensifies care for the environment, and increases the attractiveness of the agglomerations served by the analyzed plants. The obtained results were confirmed by statistical tests.

1. INTRODUCTION

The most important objective of wastewater treatment is environmental protection. This concept is closely related to the quantitative and qualitative protection of surface water and groundwater. Water plays a very important role in ecosystem processes and is an essential element of the environment, so caring for it is an essential part of environmental protection [1, 2]. The treatment of domestic wastewater usually involves the

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use of various technologies to remove suspended solids and organic and biogenic compounds. The removal of the latter is often problematic, especially in medium-sized facilities [3], which is the reason for the decision to modernize many facilities in order to obtain the appropriate quality of treated wastewater [4]. The reason for the extension of the wastewater treatment plant is also the development of sewage systems, which improves the standard of living of the residents and allows for the efficient collection and disposal of liquid contaminants, replacing the holding tanks that are common in the absence of collective sewage systems. The modernization of wastewater treatment plants also enhances environmental conditions by improving water [5]. The reconstruction of treatment systems is usually carried out using modern [6]. Each municipality, with a defined environmental policy, should strive to successively reduce the degradation of the natural environment. One of the elements of these activities is the construction or modernization of municipal wastewater treatment plants.

Water and wastewater management in municipalities is regulated in Poland by legal acts that define obligations in this regard. These are primarily: *Act on Water Law* [7], *Act on Environmental Protection Law* [8], *Act on Municipal Self-Government* [9], *Act on Maintaining Cleanliness and Order in Municipalities* [10], *Act on Collective Water Supply and Collective Wastewater Treatment* [11]. The treatment plant, which is to serve the purpose of disposing of wastewater from the site, must maintain the quality of the treated wastewater under the Regulation *The conditions to be met when discharging wastewater into the water or the ground…* [12]. The basis of EU law is the EU Directive establishing a framework for Community action in the field of water policy and the EU Directive on municipal wastewater treatment. An important document is the *National Programme for Municipal Wastewater Treatment* [13], which set out measures to achieve the adequate quality of the treated wastewater, to ensure the removal of 75% of the nutrient load, to build collective and individual sewage systems and to manage wastewater sludge in the environment. The program turned out to be very financially demanding and has already been updated for the seventh time. Concerning wastewater sludge disposal, the National Waste Management Plan [14] was developed, specifying the directions of actions for the coming years, which sets the planned expenditure related to waste management until 2028 at about 4 billion euros (PLN 17.285 billion).

Due to the requirements, wastewater treatment facilities require not only proper operation but also periodic modernization to upgrade and increase the use value of the facilities. In the *Act on Construction Law* [15], the term modernization falls within the conceptual scope of renovation, reconstruction, or extension. These terms include activities that result in a change in the usable parameters of a construction object (reconstruction) or a change in the characteristic parameters of a given object (extension). Poland's accession to the European Union has initiated many changes in the scope of water and wastewater management. Many new wastewater treatment plants have been built and existing plants have been modernized, examples of which are the treatment plants in Trzcianka, Antoniów, Miłosław, Tuchorza [16], Grotniki [3], Otwock [17], or

Ciechanów [18]. Some of the most recent examples of modernization in the Wielkopolska Region include the wastewater treatment plants (WWTP) in Rawicz and Kościan. The presented study aimed to assess the modernization of the wastewater and sludge lines of the treatment plants carried out and to indicate the impact of these activities on the water and wastewater management of the municipality.

2. MATERIALS AND METHODS

Municipal Wastewater Treatment Plant in Rawicz. The WWTP in Rawicz covers an area of 5 hectares; it receives wastewater from the town of Rawicz and 11 towns in the agglomeration covered by the combined sewage system. The treated wastewater is discharged through a system of drainage ditches into the Masłówka River, a right-bank tributary of the Orla River.

The treatment plant was built in 1975 as a mechanical treatment plant, consisting of grids, a sand trap, and an Imhoff settling tank. In 2014, the treatment plant was extended and a mechanical-biological system was created, consisting of an inflow chamber and a catchment station, a grid building equipped with a mechanical and manual grid, a horizontal sand trap with a sand separator, an Imhoff settling tank with a storm overflow in the mechanical part and a bioreactor in the form of a reinforced concrete tank with a centrally integrated secondary settling tank and an additional free-standing settling tank. The processes of removing organic compounds, nitrification and denitrification were carried out simultaneously in the reactor. The primary and secondary sludge was directed to thickeners and from there to a sludge dewatering station equipped with a belt press and decanter centrifuge, then to plots and for agricultural or natural use.

A further thorough modernization of the facility was carried out between 2019 and 2020. There were changes in all parts of the treatment plant.

In the scope of the mechanical part, the storm overflow in front of the treatment plant was constructed, the catchment station was equipped with measuring apparatus, the mechanical grids were replaced, the secondary settling tank was reconstructed into a retention tank and overflow chambers for excess wastewater were constructed, new centrifugal sand traps and a storage facility for screenings and sand were constructed and the main pumping station was reconstructed.

In the scope of the biological part, the existing bioreactor was reconstructed to create predenitrification and dephosfatation chambers to introduce separated denitrification instead of simultaneous denitrification, the surface aeration system was replaced with a fine-bubble aeration system, a second bioreactor with a wastewater separation chamber was constructed, two secondary radial settling tanks, a blower station, a pumping station for treated wastewater and recirculated sludge were constructed, and an additional external source of organic carbon was introduced to achieve the full denitrification required.

In the scope of the sludge part, the gravity thickeners and the sludge mechanical dewatering building were reconstructed and equipped with new equipment, the dewatered sludge storage facility was constructed, the lime silo was replaced and a biofilter was constructed to minimize malodorous air (Fig. 1).

Fig. 1. View of the WWTP in Rawicz after modernization

Municipal Wastewater Treatment Plant in Kościan. The WWTP in Kościan was built in 1966 as a mechanical plant, consisting of a grid chamber and an Imhoff settling tank. After the extension was completed in 1997, a mechanical and biological facility was built, consisting of a grid chamber with a stepped and emergency manual grid and a screenings press, a centrifugal sand trap, a wastewater pumping station, an Imhoff settling tank, and a biological block with anaerobic, anoxic and aerobic reactors for the removal of organic and biogenic compounds and a secondary radial settling tank; in the sludge part, gravity thickeners for sludge and a sludge dewatering station with a belt press were installed.

Due to the overload of the treatment plant, ineffective operation of the sand trap and primary settling tank, and wear and tear of the devices and equipment, a thorough modernization and reconstruction of the system was carried out in 2019. In the mechanical part, new stepped grids were installed in the grid chamber, the main pumping station was modernized, and two horizontal sand traps with a grease separator and two longitudinal primary settling tanks were constructed. In the biological part, the reactors were modernized by, among other things, introducing a tubular aeration system with the possibility of precise regulation and adding a chamber for mixing wastewater with return sludge. The automatic recirculation with measurement of the quantity of return sludge was introduced. The secondary settling tanks were also modernized and an underground effluent collector for treated wastewater was constructed. In the sludge part, the sludge pumping station was modernized and the former Imhoff primary settling tank was reconstructed into a sludge tank. The gravity thickeners of the primary sludge were modernized, and a mechanical thickener was used to thicken the excess sludge. Two sludge digesters (the so-called WKF), a sludge tank, and a chamber press were also built. Biogas, after desulfurisation, is collected from the tank and used for energy production (Fig. 2).

Fig. 2. View of the WWTP in Kościan after modernization

Research methods. The study assessed the impact of the modernization of WWTP in Rawicz and Kościan on the wastewater management of municipalities, by analyzing the quantity and quality of wastewater flowing into and out of the plants before and after the modernization, and the efficiency of contaminant removal. The data used in the study comes from the archives and current materials of Water Supply and Sewage Treatment Plant, Ltd. (Zakład Wodociągów i Kanalizacji sp. z o.o.) in Rawicz and from the Kościańskie Water Supply Company, Ltd. (Przedsiębiorstwo Wodociągowe Wodociągi Kościańskie Sp. z o.o.).

The data from two years before the modernization of the WWTP in Rawicz (2017 and 2018) and two years after the modernization (2021 and 2022) were analyzed. The quantity of wastewater was determined through the results of measurements of average daily flows of treated wastewater from the treatment plant made available and compared with the quantity estimated based on data received from the Water Supply and Sewage Treatment Plant, Ltd. regarding water consumption in the towns covered by the sewage system in the Rawicz agglomeration. The quality tests for raw and treated wastewater were performed at the accredited Environmental Laboratory in Pszczyna. For the analysis of individual contaminant indicators, the laboratory uses test methods following PN-EN standards (total suspended solids (TSS) – gravimetric method according to PN--EN 872:2007, chemical oxygen demand (COD_{Cr}) – spectrophotometric method according to PN-ISO 15705:2005, biochemical oxygen demand (BOD_5) method according to PN-EN ISO 5815-1:2019-12, total phosphorus (P_{tot}) – continuous flow analysis (CFA) method with spectrophotometric detection according to PN-EN ISO 15681-2:2006, inductively coupled plasma mass spectrometry method according to PN-EN ISO 17294-

-2:2016-11, total nitrogen (N_{tot}) – method according to PB-DAN-17, chemiluminescent method according to PN-EN 12260:2004).

In the case of the treatment plant in Kościan, the data from three years before the modernization (2016–2018) and three years after the modernization (2020–2022) were analyzed. Sampling was carried out using automatic samplers and similarly as for the treatment plant in Rawicz, the wastewater quality analyses were performed using methods compliant with PN-EN standards and carried out by an accredited laboratory belonging to the company operating the plant.

Based on the obtained results, the average values of contaminant indicators supplied to the treatment plant in the compared periods and the efficiency of removal of individual components were calculated, along with the standard deviation of the average. The Shapiro–Wilk test was used to examine the normality of the distribution of the analyzed indicators, and the non-parametric Wilcoxon test was used to compare the results obtained before and after the modernization of the plant. The null hypothesis was that there were no differences in the quality of wastewater before and after the modernization of the treatment plant.

3. RESULTS AND DISCUSSION

3.1. MUNICIPAL WASTEWATER TREATMENT PLANT IN RAWICZ

The municipal wastewater from the agglomeration flows into the WWTP in Rawicz. Estimation of wastewater volume before modernization may have been subject to large errors due to improper installation of measuring devices. Hence, the average wastewater volume before the modernization was assumed based on the quantity of water consumed as 2965 m^3/day; after the modernization, the measured volume of wastewater was 4100 m^3/day.

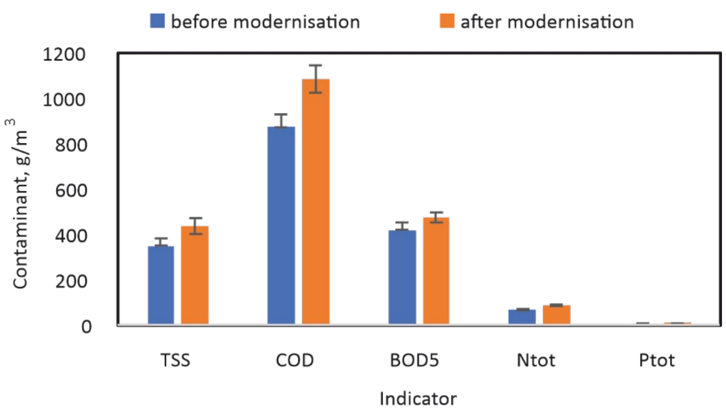

Fig. 3. Average values of the contaminant indicators at the inflow of the treatment plant before and after the modernization of the WWTP in Rawicz

The average values of the contaminant indicators at the inlet of the treatment plant before and after the modernization are shown in Fig. 3. The concentrations of contaminants flowing into the treatment plant increased, and consequently, the contaminant loads also increased – by a dozen or so (for organic and biogenic compounds) and more than 20% (for suspended solids).

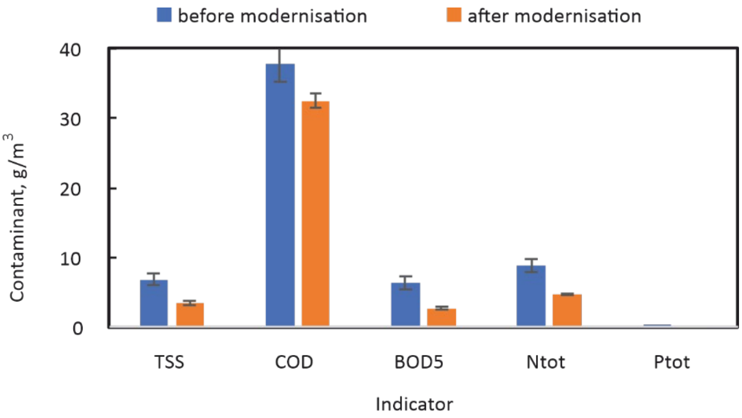

Fig. 4. Average values of the contaminant indicators at the outflow of the treatment plant before and after the modernization of the WWTP in Rawicz

However, after the modernization of the plant, despite higher inlet loads, the contaminant indicators at the outlet decreased (Fig. 4). The greatest difference was found for suspended solids, easily decomposable organic compounds (BOD_5), and nitrogen.

The effect of the above change is an increase in contaminant removal efficiency, which is a consequence of the higher efficiency of the modernized or reconstructed facilities. The greatest difference was found for total nitrogen (Fig. 5).

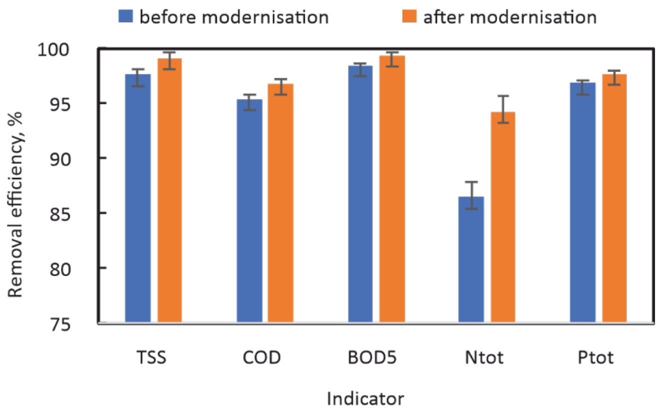

Fig. 5. Degree of reduction of contaminant indicators before and after the modernization of the WWTP in Rawicz

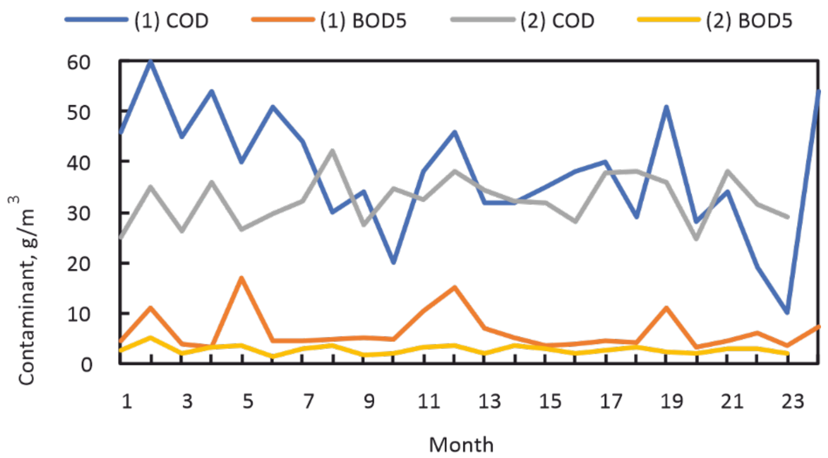

Fig. 6. Content of organic compounds in treated wastewater in the WWTP in Rawicz in the analyzed periods; 1 – before modernization, 2 – after modernization

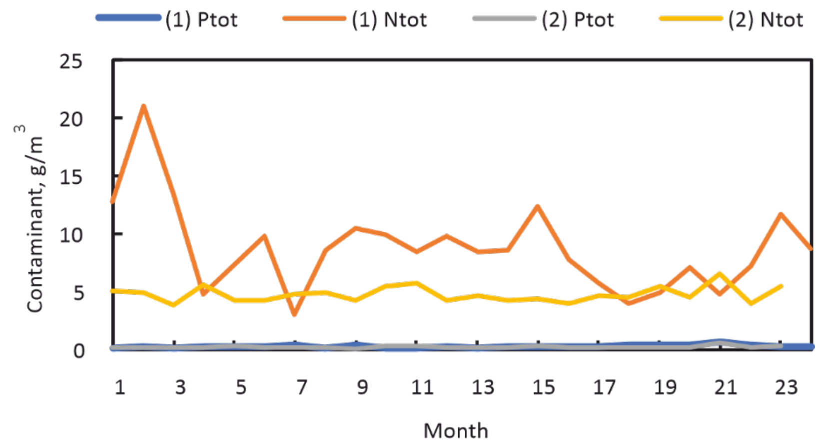

Fig. 7. Content of biogenic compounds in treated wastewater in the WWTP in Rawicz in the analyzed periods; 1 – before modernization, 2 – after modernization

To statistically evaluate the obtained results, the normality of the distribution of the collected data was determined using the Shapiro–Wilk test. As it turned out that most of the data had a non-normal distribution, the non-parametric Wilcoxon test was used to further analyze changes in the quality of wastewater, as assumed earlier. The test verified hypothesis H_0 – there are no differences between measurements and H_A: there are statistically significant differences between measurements. The test was conducted at a significance level of $\alpha = 0.05$. Based on this statistical analysis, it was found that the null hypothesis cannot be rejected in the case of COD and phosphorus, which means that there is no statistically significant difference between the results obtained for these parameters before and after the modernization of the treatment plant. In contrast, the difference between the content of total nitrogen, suspended solids and organic compounds determined as BOD_5 in the treated wastewater before and after the modernization is statistically significant. It was also found that the difference between the efficiency of contaminant removal in both facilities was statistically significant. After modernization, the treatment plant in Rawicz operates more stably, which can be seen in Figs. 6 and 7. The differences between the individual contaminant indicators after modernization are small, about a dozen or so percent, whereas previously the fluctuations were many times higher. The above observation is confirmed by the standard deviations marked in Figs. 4 and 5.

One of the effects of the modernization of the treatment plant in Rawicz is a reduction in the volume of sludge after treatment. This is due to the replacement of equipment and a more efficient sludge dewatering process. This is even more important because the sludge is used for agricultural and natural purposes by an external company, which financially burdens the company. In the future, it would be a good solution to further dispose of the sludge on site, e.g., by solar drying, which will significantly reduce the volume of the sludge and make it easier to transport and use.

3.2. MUNICIPAL WASTEWATER TREATMENT PLANT IN KOŚCIAN

The wastewater from the agglomeration also flows into the WWTP in Kościan. The average daily volume of wastewater before modernization was 4221 m^3/day, while after modernization, it was 4817 m^3/day, with the designed maximum flow rate of 8400 m^3/day. The average contaminant indicators at the inlet of the treatment plant before and after the modernization are shown in Fig. 8.

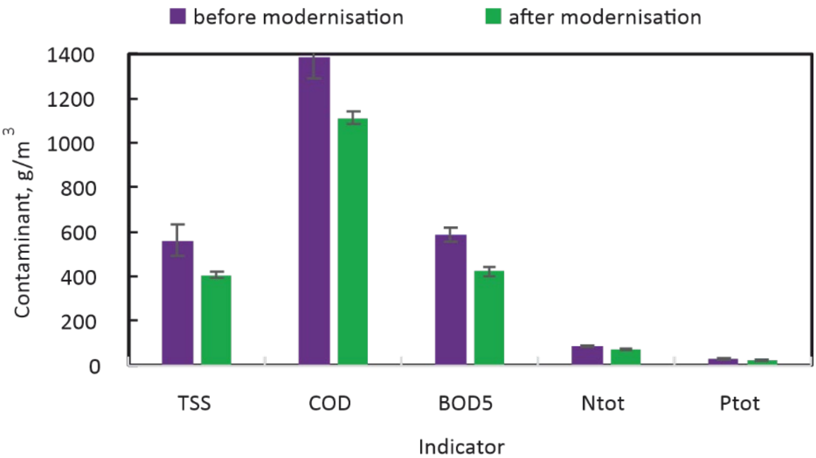

Fig. 8. Average values of the contaminant indicators at the inflow of the treatment plant before and after the modernization of the WWTP in Kościan

Figure 9, in turn, shows the average values of contaminant indicators at the outlet of the treatment plant.

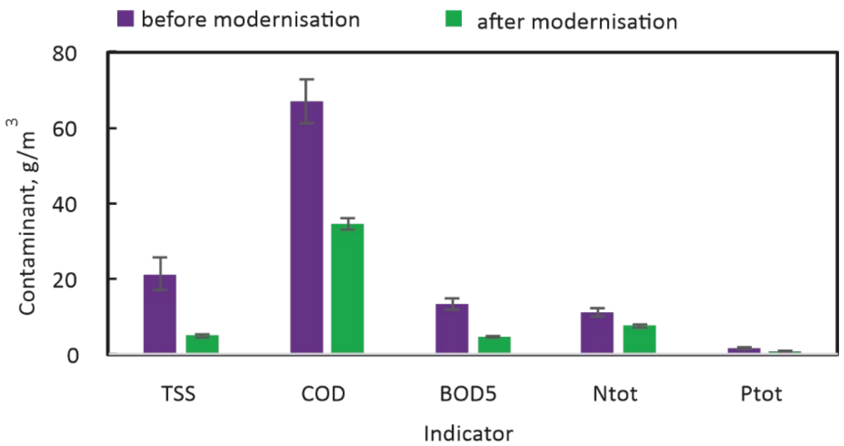

Fig. 9. Average values of the contaminant indicators at the outflow of the treatment plant before and after the modernization of the WWTP in Kościan

Although the contaminant indicators decreased from 12 to less than 30%, at the outlet, they decreased from 50 to almost 80%. The effect of these changes was an increase in the efficiency of the modernized or reconstructed treatment plant equipment (Fig. 10).

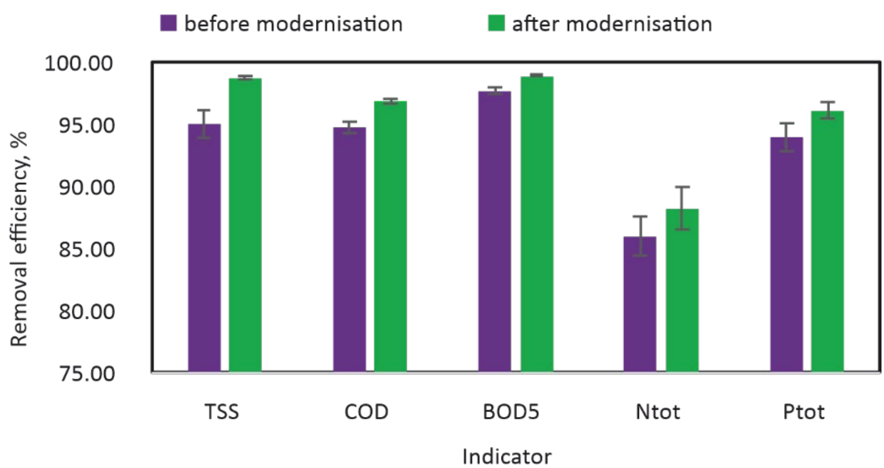

Fig. 10. Degree of reduction of contaminant indicators before and after the modernization of the WWTP in Kościan

To statistically evaluate the results, the non-parametric Wilcoxon test was used, as assumed. This was because the Shapiro-Wilk Test showed that the collected data had a non-normal distribution. Based on the test, it was found that the contaminant indicators for the treated wastewater before and after modernization differed significantly. However, the contaminant removal efficiency increased meaningly for organic compounds and total suspended solids, while for biogenic compounds, the difference was statistically insignificant.

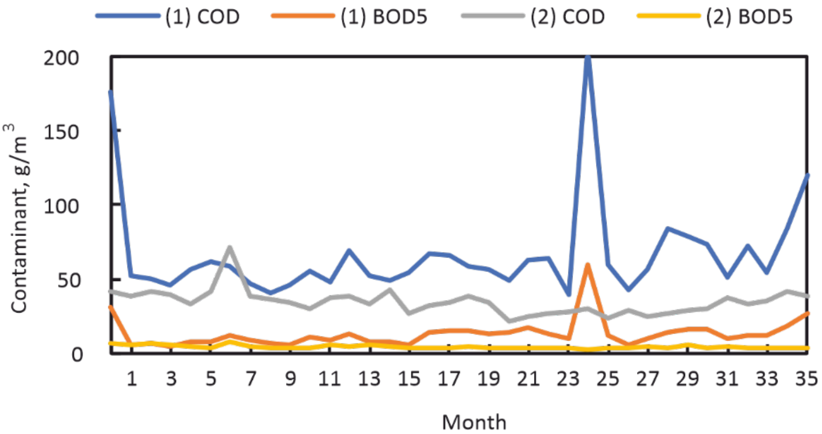

Fig. 11. Contents of organic compounds in treated wastewater in the WWTP in Kościan in the analyzed periods; 1 – before modernization, 2 – after modernization

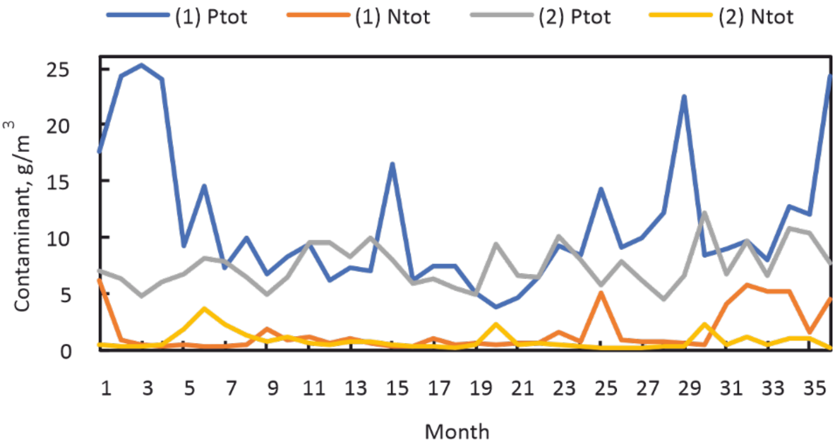

Fig. 12. Contents of biogenic compounds in treated wastewater in the WWTP in Kościan in the analyzed periods; 1 – before modernization, 2 – after modernization

After the modernization, the stability of the treatment plant's operation improved, as can be seen in Figs. 11 and 12. The differences between subsequent contaminant indicators are smaller, which is confirmed by the values of standard deviation for the analyzed groups of concentration and efficiency results, marked in Figs. 9 and 10.

4. CONCLUSIONS

The modernization of the two municipal wastewater treatment plants discussed involved the reconstruction of existing elements of the treatment plant, the replacement of equipment such as grids or centrifuges, and the construction of facilities necessary for the proper conduct of the wastewater treatment and sludge treatment processes. In addition, the treatment plants were equipped with new equipment in the form of wastewater and sludge pumps and pumping stations, wastewater and sludge retention tanks, and auxiliary equipment for waste treatment and management, such as a press for screenings or a sludge liming station.

Table 1

Elements and efficiency of the analyzed treatment plants before and after modernization

Item	WWTP in Rawicz	WWTP in Kościan
Before modernization		
Flow, m^3/day	2965	4100
Technology		
Mechanical part	stepped rack, grit chambers, Imhoff settler	rack and stepped rack, centrifugal grit chambers, Imhoff settler
Biological part	activated sludge reactor with N and P removal, radial sedimentation tank combined and separated	activated sludge reactor with N and P removal, radial settling tank
Sludge part	gravity thickeners, dewatering on a decanter centrifuges and belt press	gravity thickeners, belt press
Removal efficiency, %		
TSS/BOD_5/COD	97.6/98.4/95.4	94.9/97.7/94.7
N/P	86.5/96.9	85.9/93.9
After modernization		
Flow, m^3/day	4100	4817
Technology		
Mechanical part	stepped rack, vortex grit chambers	stepped rack, grit chambers, horizontal settling tank
Biological part	activated sludge reactors, separated N and P removal, separated radial settling tanks	biological reactor with activated sludge with N and P removal, radial settling tank
Sludge part	gravity thickener, dewatering on a decanter centrifuges	gravity and mechanical thickener, separate digester chamber, chamber press
Removal efficiency, %		
TSS/BOD_5/COD	99.1/99.4/96.8	98.7/98.9/96.8
N/P	94.2/97.7	88.2/96.1
Decrease of discharged load, %		
TSS/BOD_5/COD	33/43/0	73/61/40
N/P	28/0	22/40

Table 1 summarises the elements comprising the technological systems. Before modernization, both treatment plants had similar equipment. At present, the plants operate at similar hydraulic loads using similar technologies, except for the more extensive sludge treatment line in Kościan. It is worth noting that the treatment plant in Kościan still has a capacity reserve, as the nominal flow assumed in the design is 7000 m^3/day.

In both cases, the modernization increased the capacity of the plants and introduced modern and more energy-efficient equipment. The quality of treated wastewater also improved, and the differences between wastewater parameters at the outlet of the treatment plants and the differences in contaminant removal efficiency proved to be mostly statistically significant (Table 2). The major change in the efficiency of nitrogen removal in the treatment plant in Rawicz after changing the simultaneous nitrogen removal system to a separate nitrogen removal system.

Table 2

Results of the test of the significance of differences between parameters for the analyzed WWTP before and after modernization

Parameter	WWTP in Rawicz	WWTP in Kościan
TSS	+	+
BOD_5/COD	+/–	+/+
N/P	+/–	+/+
Removal efficiency		
TSS	+	+
BOD_5/COD	+/–	+/+
N/P	+/–	–/–

Signs + and – mean statistically significant and insignificant differences, respectively.

In turn, sludge digesters built in the treatment plant in Kościan allowed the recovery of energy in the form of digester gas and improved the energy balance of the treatment plant. The sludge from both treatment plants can be used for agriculture or natural purposes. As these are medium-sized facilities, the construction of solar dryers (in Kościan using energy from biogas) may be considered in the future to facilitate periodic storage and transport of sludge and enable the energy use of the dried material.

The modernization of the treatment plant will undoubtedly affect the quality of surface water in the vicinity of the facility, which will translate into an improvement in the quality of water collected for domestic purposes. The contaminant load discharged with the treated wastewater decreased from more than 20% to more than 70%; smaller or insignificant changes for the treatment plant in Rawicz are associated with an increase in hydraulic load by approx. 25% and with higher values of pollution indicators on the inflow. An important effect of the above changes is an increase in the standard of living of residents and an increase in the investment attractiveness of the region.

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