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An analysis of the operation of the wastewater treatment plant in Nowy Sącz – tools for assessing the efficiency and reliability of operation

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Abstract

The objective of this study was to assess the functionality of the wastewater treatment plant in Nowy Sącz by means of tools to determine the efficiency and reliability of the operation of the analysed facility. The range of analysed indicators included the main indicators of wastewater pollution: BOD_5, COD_{Cr}, total suspended solids, total nitrogen and total phosphorus. The performance of the analysed treatment plant was evaluated based on the results of the three years 2017–2019. The percentage reduction efficiency and the technological reliability coefficients of the treatment plant were determined using the values of pollutant concentrations in raw and treated wastewater. A reliable level of operation of the analysed facility was found (the resulting reliability coefficient values $WN = 0.31–0.77$) with high efficiency of wastewater treatment (reduction of analysed pollutants η = 83.03% to 99.62%). The limit values were not exceeded, which is a requirement of the applicable legislation. The method of determining technological reliability and the reduction of particular pollutants is an easy and important tool for assessing the operation and performance of wastewater treatment plants.

Keywords: wastewater treatment plant, treatment efficiency, pollutant reduction rate, technological reliability factor

1. Introduction

Environmental polution has recently been on the increase, which is mainly due to accelerated industrialisation, urbanisation and global population growth (Almond, et al., 2022). This fact makes the proper treatment of wastewater one of the most important environmental issues (Angelakis, Gikas, 2014; Pssarou, et al., 2018; Taheriyoun, Moradinejad, 2015). The reliable and efficient operation of any wastewater treatment plant is of paramount importance due to the role that this facility plays in the water and wastewater management of a municipality and region. Any malfunctioning or insufficiency of treatment has a direct negative impact on the environment and consequently, on human health and life. According to Heindrich and Witkowski (2005), treated wastewater that enters the environment should not alter the physical, chemical or biological properties of the receiving waters. Any hydrological disturbance is extremely harmful to both the community and the environment. Even worse, following increasing urbanisation and climate changes, this disturbance may continue to be a source of aggravation (Sterk, et al. 2016; Mahaut, Andrieu, 2019). The greatest threats present in domestic and industrial wastewater include toxic substances, parasites and heavy metals as well as any substances that disrupt the natural balance of the surface-water environment (Miksch, Sikora 2010; Caicedo, et al., 2019). Reducing the negative impact of wastewater entering the environment is possible with a properly designed and operated wastewater treatment plant, which is characterised by high efficiency of wastewater treatment (Chmielowski, Satora, Wałęga, 2009).

In light of the current legal regulations, maintaining high efficiency of wastewater treatment requires that its operators continuously monitor the processes taking place at the facility. Meeting the requirements for proper efficiency, stability and reliability of the operation of the facility is particularly important to ensure proper protection of the receiving water quality and, consequently, the protection of the entire aquatic ecosystem of the region (Śliz, Bugajski, 2022). When any malfunction of a wastewater treatment plant occurs, its cause has to be determined as soon as possible and immediate action has to be taken to eliminate the problem (Budkowska, et al., 2012). However, it remains important for the wastewater treatment plant operator to control the performance of a particular plant as quickly and easily as possible. To assess the performance of a wastewater treatment plant, the values of the pollutant indicators in the treated wastewater are usually compared to the limit values as provided for in the applicable legislation. This method is not without drawbacks, yet it is still one of the quickest and easiest ways to verify the performance of a treatment plant (Śliz, 2020). Knowing the changes in the values of the pollutant indicators of treated wastewater in relation to their values in raw wastewater makes it possible to assess the proper operation of a given treatment plant (Chmielowski, Młyńska, Młyński, 2015).

The objective of this study was to analyse the performance of one of the largest wastewater management facilities in the Nowy Sącz region, i.e. the Wastewater Treatment Plant in Nowy Sącz, in terms of the efficiency and technological reliability of wastewater treatment at the facility. Determination of changes in the values of selected indicators in raw and treated wastewater against the permissible values as provided for in the water use permit (*Pozwolenie*..., 2015) and in the applicable regulations (Dz.U. 2014 poz. 1800, Dz. U. 2019 poz. 1311) allowed us to determine the reduction rate of the analysed pollutants and to establish the coefficient of technological reliability of wastewater treatment in the analysed facility in the period 2017–2019. The tools used enabled us to easily and quickly verify the effectiveness and reliability of the analysed facility's operation.

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2. Characteristics of the analysed facility

The analysed facility is a mechanical-biological wastewater treatment plant in Nowy Sącz, which neutralises municipal wastewater from the city of Nowy Sącz and the surrounding area. The treatment plant was commissioned in 1996 with the main purpose of protecting the waters of Jezioro Rożnowskie and collecting domestic and industrial wastewater from the city of Nowy Sącz. The treatment plant was modernised in 2005, as a result of which, the equivalent population increased from 150,000 to 180,000. During the period under study, the average annual value of EP was 155,565.

The technological process of the treatment plant is the mechanical, biological and chemical treatment of wastewater, the treatment of sludge for its stabilisation and dewatering, and the proper management of wastewater treatment waste. The designed average 24-hour flow is 30,000 $m^3 \cdot d^{-1}$, and the actual capacity is from 23,000 to 25,000 $m^3 \cdot d^{-1}$. The average daily inflow of treated sewage in 2017, 2018 and 2019 was: 23,327; 21,289 and 24,421 $m^3 \cdot d^{-1}$. Following the modernisation, the treatment plant was extended with (among other things) a second digester with a heat exchanger with a capacity of 3,000 m^3, a new biogas tank with a capacity of 1,040 m^3, and biogas desulphurisation plants.

The treated wastewater from the treatment plant in Nowy Sącz is released into the Dunajec River (km 103+600) (*Oczyszczalnia Ścieków w Nowym Sączu*..., *Pozwolenie*..., 2015). According to the provisions of the current Water Use Permit [2015], the values of the pollution indicators of the wastewater discharged into the Dunajec River must not exceed: BOD_5 15.0 $mgO_2 \cdot dm^{-3}$, COD_{Cr} 125.0 $mgO_2 \cdot dm^{-3}$, total suspended solids 35.0 $mg \cdot dm^{-3}$, total nitrogen 10.0 $mgN \cdot dm^{-3}$ and total phosphorus 1.0 $mgP \cdot dm^{-3}$.

3. Materials and methodology

The results of physical and chemical tests of raw and treated wastewater from the analysed period 2017 to 2019 were used to determine the efficiency parameters and reliability of wastewater treatment processes at the wastewater treatment plant in Nowy Sącz. The analysed indicators included the main indicators of wastewater pollution – BOD_5, COD_{Cr}, total suspended solids, total nitrogen and total phosphorus. For each of the indicators, minimum, average and maximum value was determined and compared with the limit values, and the number of cases when these values were exceeded was reported.

The reduction rate of the analysed pollutant indicators in the treated wastewater, which was used to directly determine the treatment efficiency, was calculated according to the following formula:

$$\eta = \frac{S_s - S_o}{S_s} \cdot 100\% \qquad (1)$$

where: η – reduction of a particular pollutant index in treated sewage [%]; S_s – value of the pollution index in raw sewage [$mg \cdot dm^{-3}$]; S_o – value of the pollution index in treated sewage [$mg \cdot dm^{-3}$].

To determine the reliability of the processes taking place in the tested sewage treatment plant, the technological reliability coefficient was used, calculated from the following dependence:

$$WN = \frac{x_{śr}}{x_{dop}} [-] \qquad (2)$$

where: WN – plant reliability factor [–]; $x_{śr}$ – average value of the analysed pollution index in treated sewage [$mg \cdot dm^{-3}$]; x_{dop} – permissible value of the analysed pollution index in treated sewage [$mg \cdot dm^{-3}$].

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Results

Summary of descriptive statistics for the primary indicator BOD_5, which determines the organic matter content of wastewater, is presented in Table 1.

Table 1. Summary of basic descriptive statistics of BOD_5 values in raw wastewater and after treatment at the analysed treatment plant

Descriptive statistics	Symbol	Value of the indicator BOD_5 [$mgO_2 \cdot dm^{-3}$]	
		in raw sewage	in treated sewage
min. value	Min	197.30	1.60
average value	$\bar{X}$	421.93	4.68
max. value	Max	675.00	9.60
number of samples	N	36	36
limit value	X_{dop}	–	15.0
cases of exceeding the limit value	LP	–	0

(Source: own elaboration)

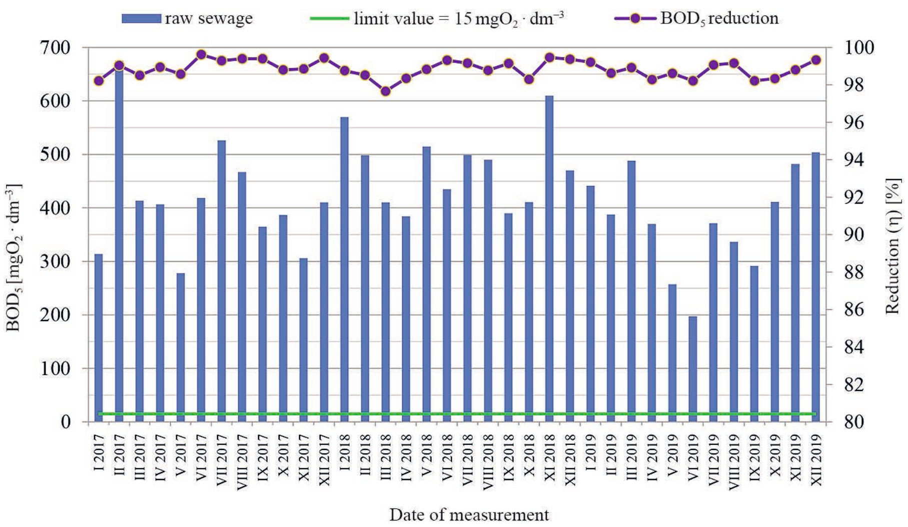

Fig. 1a. BOD_5 values in raw wastewater versus the limit value and efficiency of the reduction of the indicator at the analysed facility (source: own elaboration)

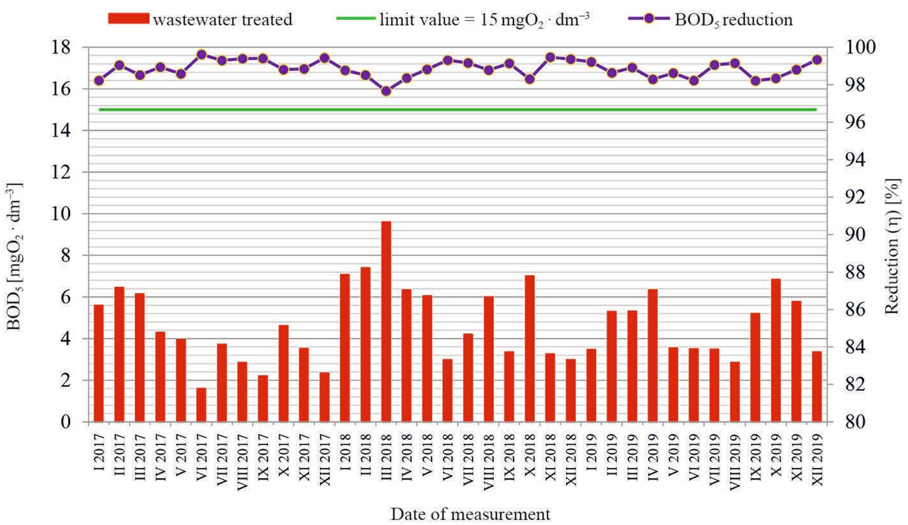

Fig. 1b. BOD_5 values in treated wastewater versus the limit value and efficiency of the reduction of the indicator at the analysed facility (source: own elaboration)

The analysis of Table 1 and Figures 1a and 1b gave the BOD5 values in the treated wastewater recorded in the range from 1.60 to 9.60 $mgO_2 \cdot dm^{-3}$, with an average value of 4.68 $mgO_2 \cdot dm^{-3}$. The BOD_5 limit values in the treated wastewater were not exceeded. The average reduction efficiency of the analysed

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indicator (η) of 97.66% proves that the requirements are met as stated in the applicable regulations (2014, 2019) on the minimum reduction of BOD_5 in wastewater discharged to receiving waters of 90%.

The analysis of another indicator of wastewater pollution (COD_{Cr}) in Table 2 and Figures 2a and 2b shows that the limit value was not exceeded.

Table 2. Summary of basic descriptive statistics of COD_{Cr} values in raw wastewater and after treatment at the analysed treatment plant

Descriptive statistics	Symbol	Value of the indicator COD_{Cr} [$mgO_2 \cdot dm^{-3}$]	
		in raw sewage	in treated sewage
min. value	Min	651.50	19.00
average value	$\bar{X}$	1067.75	44.56
max. value	Max	1819.50	68.00
number of samples	N	36	36
limit value	X_{dop}	–	125.0
cases of exceeding the limit value	LP	–	0

(Source: own elaboration)

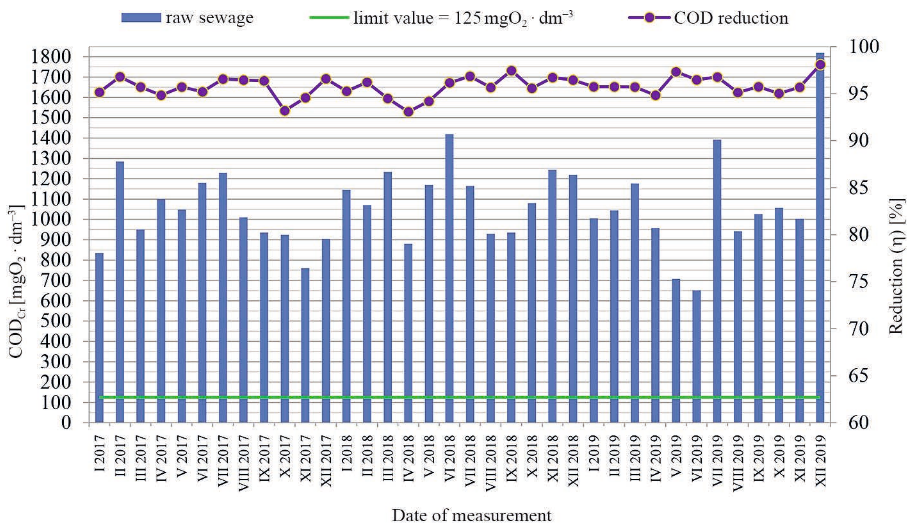

Fig. 2a. COD_{Cr} values in raw wastewater versus the limit value and efficiency of the reduction of the indicator at the analysed facility (source: own elaboration)

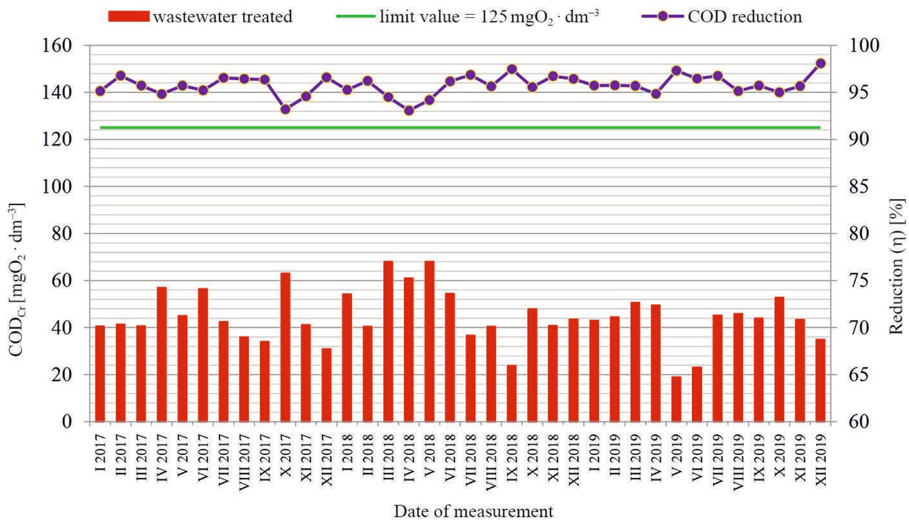

Fig. 2b. COD_{Cr} values in treated wastewater versus the limit value and efficiency of the reduction of the indicator at the analysed facility (source: own elaboration)

The average value of COD_{Cr} in raw wastewater was 1067.75 $mgO_2 \cdot dm^{-3}$ and in treated wastewater, it was 44.56 $mgO_2 \cdot dm^{-3}$. The reduction efficiency of COD_{Cr} ranged from 93.07% to 98.08% with a mean value of 93.07%. The reduction rate achieved was well above the value for discharging treated effluent into the aquatic ecosystem (75%).

Table 3. Summary of basic descriptive statistics of total suspended solids in raw wastewater and after treatment at the analysed treatment plant

Descriptive statistics	Symbol	Value of the indicator total suspended solids [mg·dm^{-3}]	
		in raw sewage	in treated sewage
min. value	Min	128.05	4.56
average value	$\bar{X}$	442.46	12.47
max. value	Max	918.00	28.75
number of samples	N	36	36
limit value	X_{dop}	–	35.0
cases of exceeding the limit value	LP	–	0

(Source: own elaboration)

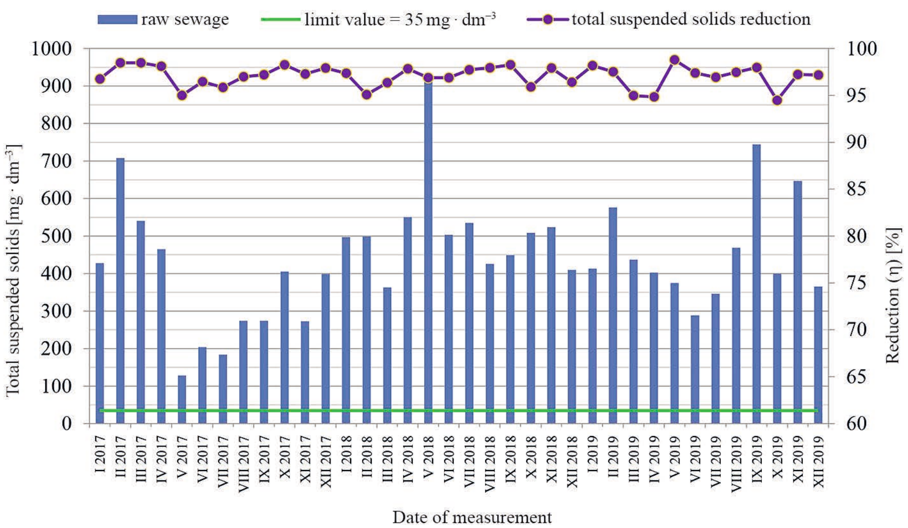

Fig. 3a. Total suspended solids values in raw wastewater versus the limit value and efficiency of the reduction of the indicator at the analysed facility (source: own elaboration)

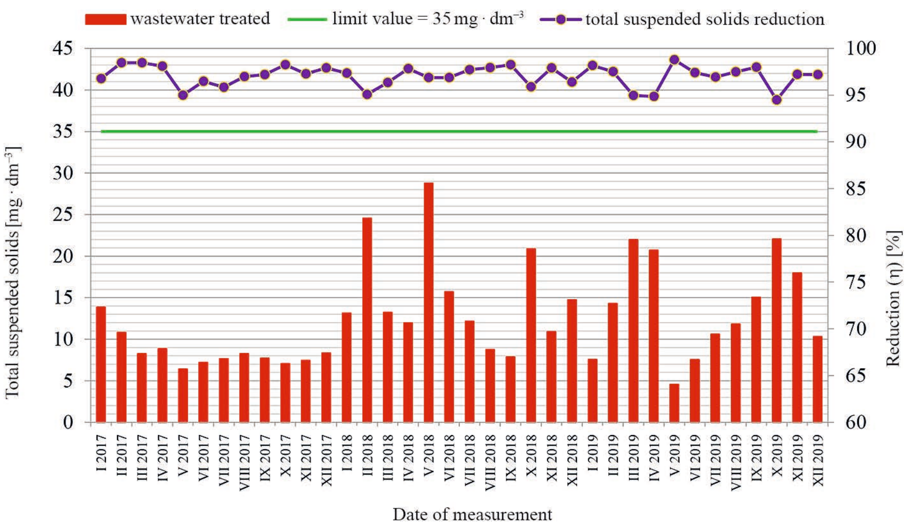

Fig. 3b. Total suspended solids values in treated wastewater versus the limit value and efficiency of the reduction of the indicator at the analysed facility (source: own elaboration)

The concentration of total suspended solids (Table 3, Fig. 3a, 3b) in the treated wastewater ranged from 4.56 to 28.75 mg·dm^{-3}, with an average value of 12.47 mg·dm^{-3}. During the analysed period 2017–2019, there was no case of exceeding the limit value according to the applicable water permit (*Pozwolenie*..., 2015). The removal efficiency of total suspended solids remained high, from 94.48% to 98.79%.

Table 4. Summary of basic descriptive statistics of the total nitrogen values in the raw sewage and after treatment at the treatment plant under study

Descriptive statistics	Symbol	Value of the indicator total nitrogen [mgN·dm⁻³]	
		in raw sewage	in treated sewage
min. value	Min	39.54	4.94
average value	$\bar{X}$	70.86	7.67
max. value	Max	93.00	9.70
number of samples	N	36	36
limit value	X_{dop}	–	10.0
cases of exceeding the limit value	LP	–	0

(Source: own elaboration)

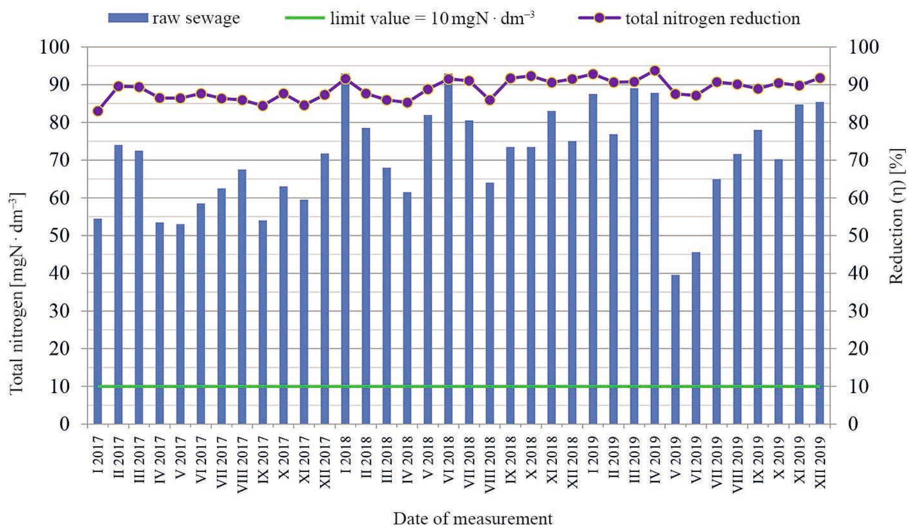

Fig. 4a. Concentration of total nitrogen in raw wastewater versus the limit value and efficiency of the reduction of the indicator in question at the investigated facility (source: own elaboration)

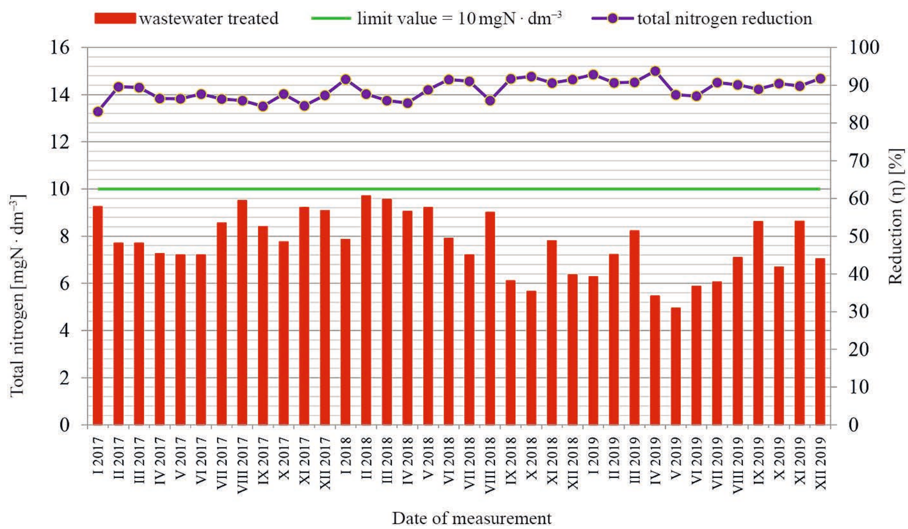

Fig. 4b. Concentration of total nitrogen in treated effluent versus the limit value and efficiency of the reduction of the indicator in question at the investigated facility (source: own elaboration)

As shown in Table 4 and Figures 4a and 4b, the concentration of total nitrogen in the effluent flowing into the studied facility ranged from 39.54 to 93.00 mgN·dm⁻³. The treated wastewater at the studied facility was characterised by values in the range from 4.94 to 9.70 mgN·dm⁻³, with an average value of 7.67 mgN·dm⁻³. In accordance with the legal acts in force (*Pozwolenie*..., 2015; Dz. U. 2014 poz. 1800; Dz. U. 2019 poz. 1311), there was no case of exceeding the permissible value and the required degree of reduction of total nitrogen was achieved, which for the treatment plant in Nowy Sącz was η = 88.81% to 93.79%.

Table 5. Summary of basic descriptive statistics of total phosphorus values in raw sewage and after treatment at the studied treatment plant

Descriptive statistics	Symbol	Value of the indicator total phosphorus [mgP·dm⁻³]	
		in raw sewage	in treated sewage
min. value	Min	3.80	0.19
average value	$\bar{X}$	8.89	0.43
max. value	Max	16.56	0.86
number of samples	N	36	36
limit value	X_{dop}	–	1.0
cases of exceeding the limit value	LP	–	0

(Source: own elaboration)

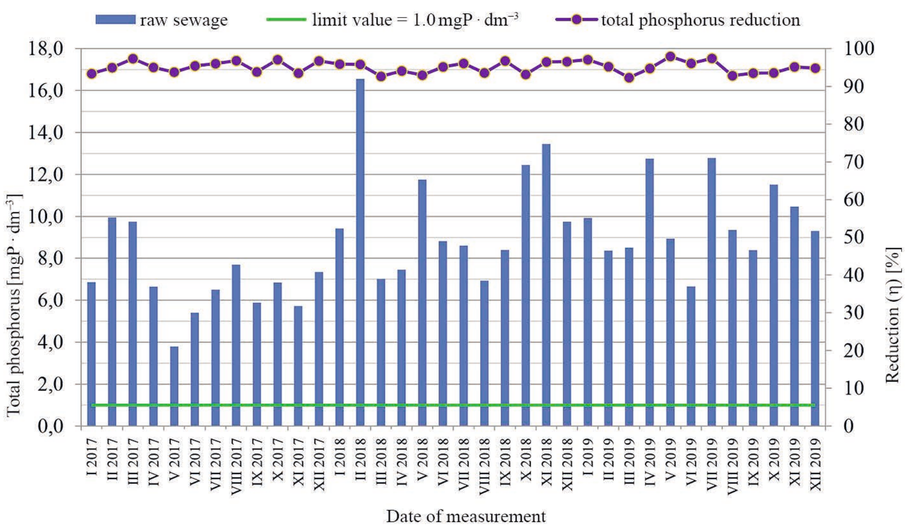

Fig. 5a. Concentration of total phosphorus in raw effluent versus the limit value and efficiency of the reduction of the indicator in question at the investigated facility (source: own elaboration)

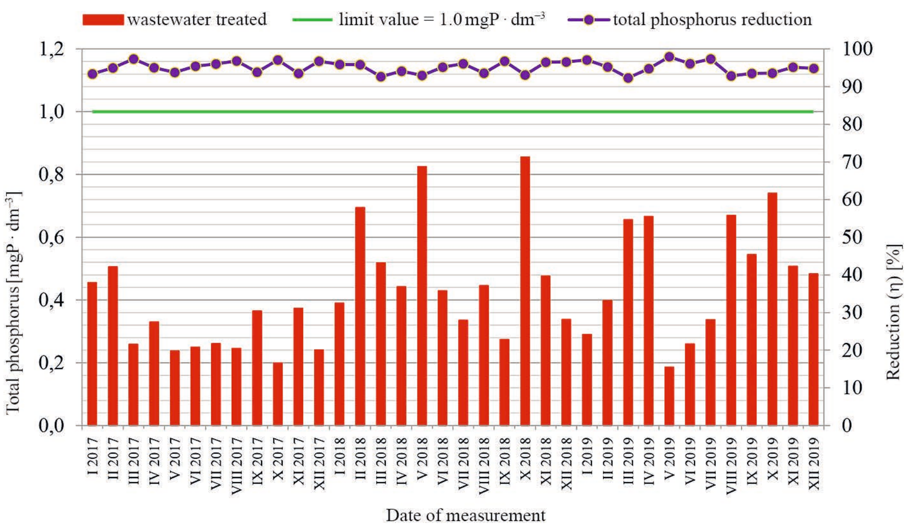

Fig. 5b. Concentration of total phosphorus in treated effluent versus the limit value and efficiency of the reduction of the indicator in question at the investigated facility (source: own elaboration)

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The average concentration of total phosphorus (Table 5, Fig. 5a, 5b) in the wastewater flowing into the analysed facility was 8.89 mgP·dm^{-3}. The treated effluent was characterised by values ranging from 0.19 to 0.86 mgP·dm^{-3}, with a mean value of 0.43 mgP·dm^{-3}. During the analysed period 2017–2019, the limit values as provided for in the applicable water use permit (*Pozwolenie*..., 2015) were not exceeded. As Figure 5 shows, the efficiency of reducing the concentration of total phosphorus in the treated effluent varied from 92.30% to 97.72%, achieving an average value of 95.10%. Thus, the condition of having to achieve a minimum reduction level of 90% set in the regulations (2014, 2019) was met.

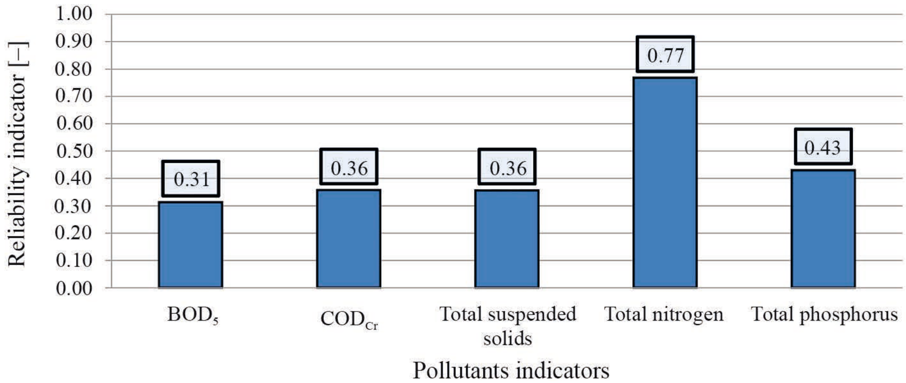

Fig. 6. Values of the technological reliability coefficient *WN* for the investigated pollutant indicators at the analysed wastewater treatment plant (source: own elaboration)

Figure 6 shows the values of the technological reliability coefficient for the analysed facility, which were determined for particular wastewater pollution indicators. The low values of the coefficient (*WN*) prove the proper efficiency of the operation of the wastewater treatment plant in Nowy Sącz. In the case of BOD_5, they amounted to only 0.31, for COD_{Cr} and total suspended solids WN = 0.36. According to Chmielowski et al. (2015), satisfactory efficiency of wastewater treatment plant operation can already be stated in the case of reliability coefficient values at: WN_{BOD_5} = 0.44, $WN_{COD_{Cr}}$ = 0.57 and WN_{TS} = 0.43. In the case of total nitrogen, the reliability coefficient reached the highest value among the analysed pollutant indicators (0.77), but it is still below 1.00, which indicates that the reliability of the nitrogen compound reduction process is maintained. The value obtained is similar to the results of Śliz (2018), where WN_{TN} = 0.81 and 0.86, and the results of Młyński et al. (2016), where WN_{TN} = 0.60, which testified to the correct operation of the studied facilities. The reliability coefficient WN for total phosphorus reached a satisfactory value of 0.43.

4. Conclusions and summary

This work has analysed the performance of a wastewater treatment plant in Nowy Sącz in the context of assessing its effective and reliable operation. Selected tools for assessing the performance of a given plant, such as the degree of pollutant reduction (η) and the technological reliability index (*WN*), allow a simple and quick assessment of the efficiency and reliability of wastewater treatment in different types of plants, regardless of size, technology or location. In the case of the analysed plant, these tools made it possible to check whether the quality of the treated wastewater met the requirements of the legislation in force, thus ensuring adequate environmental protection. Determining the value of the technological reliability index made it possible to assess the efficiency and reliability of the operation of the analysed treatment plant. Based on the analysis, the following cinclusions can be drawn:

1. In the case of all analysed pollutant indicators (BOD_5, COD_{Cr}, total suspended solids, total nitrogen and total phosphorus), the limit values were not exceeded as compared with the provisions of the Water Law Use Permit (2015). The resulting reduction rate showed high efficiency of wastewater treatment for all analysed pollutants (BOD_5: 97.7%–99.6%, COD_{Cr}: 93.1%––98.1%, total suspended solids: 94.5%–98.8%, total nitrogen: 83.0%––93.8%, total phosphorus: 92.3%–97.9%). The determination of the degree of pollutant reduction (η) made it possible to confirm that the requirements set out in the applicable regulations (Dz. U. 2014 poz. 1800; Dz. U. 2019 poz. 1311) have been met and that the treatment plant has fulfilled its primary function of effectively treating wastewater and thus protecting the environment.
2. The high efficiency of wastewater treatment in the analysed facility was also proven by the resulting reliability index (WN) values. In the case of BOD_5, COD_{Cr} and total suspended solids, technological reliability values of 0.31, 0.36 and 0.36 were recorded, proving high reliability of the removal of these pollutants. Worse results were obtained for the eutrophic indicators total nitrogen and total phosphorus, for which WN was 0.77 and 0.43, respectively.
3. On the basis of the performed analyses, the conclusion may be drawn that the tools used to determine the effectiveness and reliability of the wastewater treatment processes allow the performance of the analysed plant to be easily determined. With their versatility, these tools can be used to assess the performance of different types of wastewater treatment plants, regardless of their technical, operational or locational parameters. This contributes to the protection of water resources in any area.

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Rozporządzenie Ministra Gospodarki Morskiej i Żeglugi Śródlądowej z dnia 12 lipca 2019 r. w sprawie substancji szczególnie szkodliwych dla środowiska wodnego oraz warunków, jakie należy spełnić przy wprowadzaniu do wód lub do ziemi ścieków, a także przy odprowadzaniu wód opadowych lub roztopowych do wód lub do urządzeń wodnych, Dz. U. 2019, poz. 1311.

Rozporządzenie Ministra Środowiska z dnia 18 listopada 2014r. w sprawie warunków, jakie należy spełnić przy wprowadzaniu ścieków do wód lub do ziemi, oraz w sprawie substancji szczególnie szkodliwych dla środowiska wodnego, Dz. U. 2014, poz. 1800.

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