*Desalination and Water Treatment*
www.deswater.com

doi: 10.5004/dwt.2022.28006

246 (2022) 120–138
January

# Reliability and efficiency of the removal of pollutants in the mechanical–biological wastewater treatment plant A2/O

Magdalena Gizińska-Górna[a,*], Zbigniew Wasąg[b]

[a]*Department of Environmental Engineering and Geodesy, University of Life Sciences in Lublin, Akademicka 13, 20-950, Lublin, Poland, email: magdalena.gizinska-gorna@up.lublin.pl (M. Gizińska-Górna)*
[b]*Jan Zamoyski College of Humanities and Economics in Zamość, ul. Koszary 8, 22-400 Zamość, Poland, email: zbigniew.wasag1@wp.pl*

Received 17 June 2021; Accepted 13 November 2021

**ABSTRACT**

The aim of the research was to determine the efficiency and reliability of the removal of pollutants from wastewater by the mechanical–biological treatment plant A2/O. The system disposed of on average 4,000–5,000 $m^3$/d of wastewater, of which about 320 $m^3$/d was industrial wastewater. The evaluation was based on data from 5 y (2015–2019) of the work of this facility. The following pollution indicators were analyzed: biochemical demand for oxygen ($BOD_5$), chemical oxygen demand (COD), total suspended solids (TSS), total nitrogen (TN), total phosphorus (TP). The efficiency of wastewater treatment during the period under study was good. The pollutant reduction coefficients averaged over the years 2015–2019 were: for TSS – 95%, for $BOD_5$ – 98%, COD – 93% for TN – 82%, and TP – 88%. The results of the Weibull-based reliability analysis in the case of TSS and COD indicated that the treatment plant analyzed during the whole test period worked with high efficiency. The study showed that in the case of $BOD_5$ there were 25 d in the year in which the limit may be exceeded. Studies have shown that 44% of collected samples of treated wastewater exceeded total nitrogen concentrations of 15 mg/L. Thus, effluent discharged to the receiver from the treatment plant analyzed, on approximately 160 d during a year total nitrogen concentrations are above limit values. On this basis, it can be concluded that the treatment plant under examination does not comply with the requirements of the Regulation for almost half of the year. The cause of this condition is the instability of nitrification and denitrification processes which are responsible for the removal of nitrogen compounds in a biological reactor. In the case of the treatment plant under consideration, the reliability of the removal of general phosphorus on 55 d/y is reduced, thus the values obtained during these days are at a level that does not meet the reliability requirements.

*Keywords:* Activated sludge; Efficiency; Pollution removal; Reliability; Wastewater treatment plant

## 1. Introduction

After Poland's accession to the European Union, the obligation to bring Polish legislation in line with European Standards was imposed. The National Urban Waste Treatment Programme, adopted and introduced by the Ministry in 2005 to bring Poland in line with European standards in the field of municipal wastewater management, requires the collection and treatment of all municipal wastewater in our country. The program assumes the construction of a wastewater network with the construction of new or the expansion and modernization of the existing wastewater treatment plants.

The main task of each wastewater treatment plant is to protect water resources, as well as living organisms and their environment. Depending on the type of wastewater,

* Corresponding author.

appropriate treatment technology is selected, which should be efficient enough to achieve the highest level of treatment at the lowest possible cost. The receiver of outflow effluent is mainly flowing water, which is highly susceptible to changes caused by the introduced effluent. Changes in the chemical and physical composition of water may result in a deterioration of their quality, as well as adverse effects on all living organisms. Untreated or poorly treated effluent adversely affects water resources by limiting their continued use, therefore environmentally hazardous substances contained in the wastewater should be completely removed or their properties changed so that they do not pose any further risks.

The most important indicators of water pollution are biogenic compounds, that is, nitrogen and general phosphorus. Their presence in water poses a risk of eutrophication, as these elements are responsible for biological productivity in the aquatic environment. Their main source of surface water is municipal and industrial wastewater. This is why reducing these indicators is an important issue in wastewater treatment technology.

The resulting effect of removing pollutants from wastewater in a given technological process is the result of many physical processes and biochemical transformations that interact side by side in different ways. The operation of wastewater treatment systems requires compliance with an appropriate technical and technological regime.

The primary impact on the efficiency of wastewater treatment is the quality of raw sewage and the hydraulic load of the facility. The diversified substrate and hydraulic loads of the treatment plant often cause significant disturbances in its operation, resulting in the introduction of excessive amounts of impurities into the receiver. For this reason, high efficiency, efficiency and reliability of the removal of pollutants in the full range of their load and capacity [1] are expected from operating wastewater treatment plants [2,3].

The world's most popular biological wastewater treatment occurs with activated sludge. This solution has been used for exactly one hundred years to treat a lot of different municipal and industrial wastewater to protect our environment and human health [4–7]. Active sediment is a unique artificial microbiological ecosystem with high diversity (more than 700 types and thousands of OTU) [8] and high biomass concentrations (usually 2–10 g $L^{-1}$) [9]. Very diverse bacterial communities in this designed ecosystem are effectively aggregating in a heterogeneous structure of activated sludge flocs to ensure stable and good results of biological wastewater treatment [2,3,6,8,10–12].

The aim of the study is to analyze the reliability and efficiency of the removal of pollutants (suspension of general, biochemical demand for oxygen – $BOD_5$, chemical demand for oxygen – COD, total nitrogen and general phosphorus) in a mechanical–biological wastewater treatment plant.

## 2. Material and methods

### *2.1. Characteristics of the experimental facility*

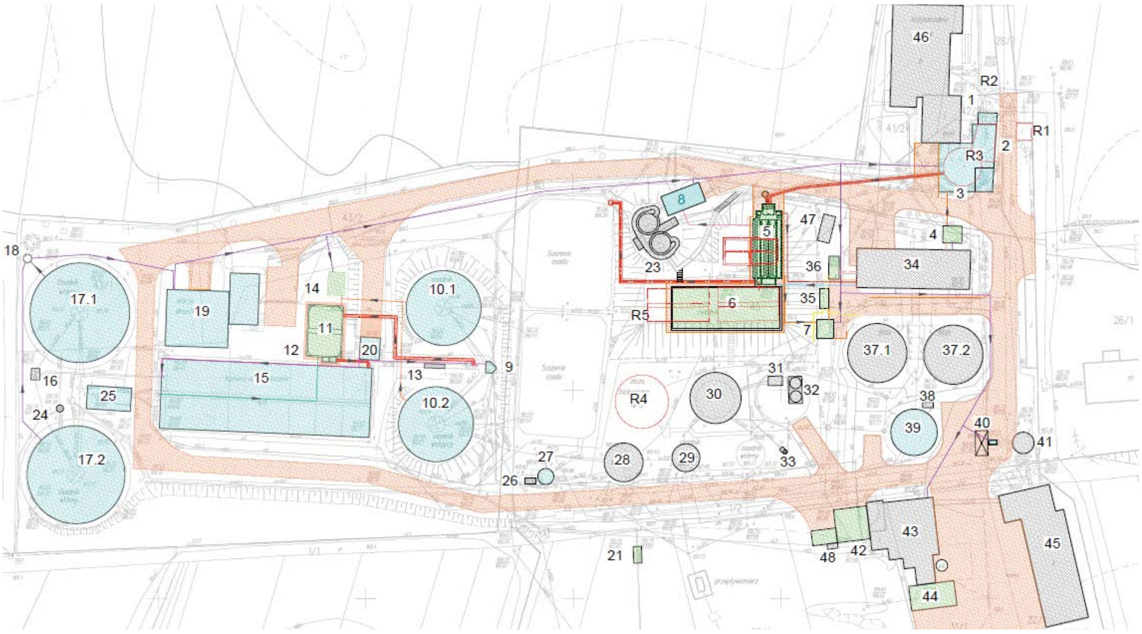
The mechanical–biological municipal wastewater treatment plant was put into service in December 1998. It operates in the A2/O system, which is used for the combined removal of nitrogen and phosphorus, and three zones are separated within it: anaerobic, anoxic, aerobic. The internal recirculation of the mixture of wastewater and sludge from the final part of the aerobic zone to the anoxic zone is between 100% and 300% of the amount of wastewater delivered to the system and increases depending on the required nitrate reduction. The recirculation of the sediment to the anaerobic zone is relatively low and is 20%–50%. A characteristic feature of the biological method of removal of phosphorus is the presence in the purification system of zones: anaerobic and aerobic. In integrated systems, in addition to defosphatation, nitrification and denitrification are located between the anaerobic and aerobic zones.

The treatment plant may take an average of 8,000 $m^3$ of wastewater per day, with a maximum of 10,000 $m^3$/d. The facility consists of two technological sequences of wastewater and they work according to needs (single or together). Treatment in one technological sequence takes place in the case of less incoming wastewater, which is beneficial, for economic reasons, as well as in the event of a technical failure, it provides the possibility of continuous operation. It may happen that the activated sludge is destroyed in one of the sequences, and the purification process will take place in the second technological sequence. The recovery time, depending on the season is about 30 d. Activated sediment is a collection of various types of micro-organisms that, as a result of their life activity, cause oxygen degradation of organic substances contained in the wastewater. The treatment of wastewater using activated sludge is carried out using two basic devices: activated sediment chambers and secondary settlers working in the flow system.

At the time of the study, the treatment plant received an average of 4,000–5,000 $m^3$/d of wastewater, of which about 320 $m^3$/d is industrial wastewater. Within the agglomeration of Biłgoraj, the share of industry is approx. 35% of the total load reaches the treatment plant (mainly meat processing facilities). Factors likely to cause such significant changes in the proportions of pollution indicators may include: the share of industrial wastewater and the problem of sampling. This facility does not have an autosampler for mid-day sampling – the sampling is carried out manually by the treatment plant personnel and without taking into account the proportionality to the flow.

Wastewater from the wastewater system and the sink station enters the screen building, where in a deep reinforced concrete chamber two mechanical stepped screens are installed, made of stainless steel, with a clearance of 5 mm and a total width of 600 mm.

After rough cleaning, the wastewater goes to the main pump room, it is the only point of raised level on the wastewater treatment path. From the main pump room, it is then pressed into a two-chamber centrifugal grit chamber, with a single chamber diameter of 5.2 m. Deposited sand from each chamber is removed hydraulically by gravity. The hydrated sand flows into the separator where it is dehydrated. There are two radial primary settling tanks with a mechanical scraper with an active capacity of 495 $m^3$ each (Fig. 1). They stop easily falling sediments with a density greater than l g/$cm^3$. The second important function of these settling tanks is the retention of substances lighter than water (fats). In addition to stopping




**Designations**

1 valve chamber, 2 screen building, 3 main wastewater pump room, 4 biofilter of the screen house and pumping station, 5 blow-through longitudinal grit chamber, 6 retention tank, 7 biofilter of the grit chamber and retention tank – designed structure, 8 separator building with grit washer, 9 wastewater separation chamber before primary settling tanks, 10.1, 10.2 primary settling tanks, 11 defosphatation chamber, 12 wastewater separation chamber before activated sludge chambers, 13 metering orifice, 14 biofilter of primary settling tanks, defosphatation chambers, 15 activated sludge chambers, 16 wastewater separation chamber before secondary settling tanks, 17.1, 17.2 secondary settling tanks, 18 technological water pumping plant, 19 blower plant building, 20 pix dosing station, 21 treated wastewater measuring chamber, 22 outlet of treated wastewater, 23 grit chamber, 24 flotate pumping station, 25 recirculate pumping station, 26 deodorization unit of the sludge consolidation tank, 27 raw sludge pumping station, 28 gravitational primary sludge consolidation tank, 29 supernatant pumping station, 30 biogas holder, 31 biogas compression node, 32 biogas desulphurizer, 33 biogas torch, 34 engine room, 35 container drying station with siloxane filters, 36 CHP unit in container housing, 37.1, 37.2 fermentation chamber, 38 deodorization unit of the fermented sludge tank, 39 fermented sludge tank, 40 draining station, 41 transported wastewater tank, 42 reception building of sludge form the cleaning of the wastewater system, 43 sludge dehydration building, 44 sludge reception area roof, 45 garage, 46 facility building, 47 garage, 48 deodorization unit of the dehydration building and of the reception of sludge from the wastewater system.

Fig. 1. Technological diagram of the mechanical–biological treatment plant in Biłgoraj.

the suspensions contained in the incoming wastewater, the primary settling tanks also have the task of removing excessive sludge that is brought to the wastewater. The settled sludge is collected and removed outside the settling tank, while the purified effluent is discharged to further treatment facilities. After mechanical pre-treatment, the wastewater enters the activated sludge chamber, which is divided into two parallel technological sequences with an active volume of 2,609.0 m$^3$. Each of the technological lines is divided into chambers: defosphatation ($V$ = 337 m$^3$), denitrification ($V$ = 337 m$^3$), optional denitrification/nitrification chamber ($V$ = 337 m$^3$), and two nitrification chambers ($V$ = 799 m$^3$) (Fig. 1). In each of the nitrification chambers and in the optional chamber, there are aeration diffusers powered by blowers from the blower station. The introduction of optional zones allows flexible adjustment of the size of denitrification and nitrification zones in the reactor according to the processing needs. Phosphorus compounds are removed from the wastewater by dosing the PIX coagulant at the end of the biological wastewater treatment chambers. The coagulant is dosed by the Maxroy Milton Roy membrane pump in a quantity dependent on the content of phosphorus compounds, whose concentration is measured by the laboratory. Wastewater at this treatment plant undergoes full biological treatment, as efficiency achieves values above 85%, usually in the range of 90%–95%. Additional measures of this degree of purification include COD loss, total organic carbon (PLA), bacteria, as well as the removal of biogenic impurities. The effectiveness of the reduction of these pollutants depends to a large extent on the composition of the treated wastewater and on the type and method of the biotreatment process.

After biological treatment, the wastewater goes to two radial secondary settling tanks with mechanical scrapers, with an active capacity of 1,112.0 m$^3$. After the secondary settling tanks, the purified effluent is discharged to the receiver, which is the Czarna Łada River. It flows from the springs in the village of Margole, from the east to the west, at the village of Sól merging with the River Biała Łada. The area of the river basin is approx. 13.6 ha, and its length is approximately 25.1 miles.

The flows characteristic of the Czarna Łada River are as follows:

- Mean low (SNQ) = 0.17 $m^3/s$,
- Mean (SQ) = 1.06 $m^3/s$,
- Mean high (SWQ) – 18.0 $m^3/s$.

On the basis of the actual loads of impurities entering the wastewater treatment plant and the acceptance of the $BOD_5$ unit load from 1 inhabitant of 0.06 $kgO_2$/person, the population equivalent of inhabitants was determined at 59,282 PE (3,557 $BOD_5$ kg/person/d).

### 2.2. Analytical methods

The amount of incoming wastewater (totalizing-registering measurement) is measured in the discharge channel from the primary settling tanks, where a flow meter with the Venturi connector was installed.

An assessment of the efficiency of the removal of pollutants in the treatment plant was carried out on the basis of the results of quality wastewater studies collected between 2015 and 2019. Test wastewater samples were collected once a month at three points: after the screen (raw sewage), after primary settling tanks (mechanically cleaned wastewater) and after secondary settling tanks (purified effluent).

In the wastewater samples, the following indicators were determined: concentration of total nitrogen, total phosphorus, the content of general suspension (TSS) and the amount of $BOD_5$ and COD. The tests were carried out according to the following standards: PN-EN 25663, PN-82 C-04576.8, PN-EN-872, PN-EN 14672 in a laboratory operating according to the ISO 9001 quality management system at the treatment plant under study.

On the basis of the results obtained, the minimum, maximum and average values, the standard deviation and the coefficient of variation were determined. The average values of the indicators analyzed for incoming waste (Cd) and discharge effluent (Co) from the treatment plant were used to obtain the mean pollution removal efficiency in the analyzed facility according to Eq. (1):

$$\eta = 100 \times \left(1 - \frac{C_0}{C_d}\right)(\%) \quad (1)$$

The analysis of the results of the studies also included an assessment of the susceptibility of wastewater entering the treatment plant to the degradation of organic pollutants, expressed by the ratio of $COD_{Cr}/BOD_5$. To this end, the average annual values of both organic compounds indices have been compared to each other. This assessment was based on the dependencies available in the literature describing the biodegradability measures of organic pollutants present in effluents, according to the following relationships [13,14]:

$COD/BOD_5 < 2.0 \rightarrow$ easy susceptibility to biological decomposition (2)

$COD/BOD_5 = 2.0 \div 2.5 \rightarrow$ average susceptibility to biological degradation (3)

$COD/BOD_5 = 2.5 \div 5.0 \rightarrow$ poor susceptibility to biological degradation (4)

$COD/BOD_5 > 5.0 \rightarrow$ inseparable matter (5)

In addition, based on average annual concentrations of total nitrogen (TN) and general phosphorus (TP), the susceptibility of wastewater to biological removal of biogenic compounds was determined in effluents prior to their introduction into the technological system. The appropriate proportion of fermentation products to nitrogen and phosphorus concentrations in wastewater is a factor that has a significant impact on their removal. For this purpose, the quotients of $TN/BOD_5$ and $TP/BOD_5$ were determined and then compared with the values given in the literature, which indicate that the processes of denitrification (5) and defosphatation (6) most effectively occur when [15,16]:

$$TN/BOD_5 < 0.25 \quad (6)$$

$$TP/BOD_5 < 0.04 \quad (7)$$

### 2.3. Statistical analysis

The assessment of the technological reliability of the treatment plant in Biłgoraj was carried out for basic indicators of impurities ($BOD_5$, COD, TSS, TN and TP) using elements of Weibull's reliability theory. The Weibull distribution is a useful general probability distribution applicable to the reliability test and the risk of exceeding the limit values for pollutants in purified effluent [17–20]. The distribution is characterized by the following probability density function:

$$f(x) = \frac{c}{b} \cdot \frac{x - \theta}{b}^{(c-1)} \cdot e^{-\frac{x-\theta^c}{b}} \quad (8)$$

where $x$ is the variable determining the concentration of a given impurity indicator in purified effluent, $b$ is the scale parameter, $c$ is the shape parameter, θ is the position parameter.

Under the assumptions: $\Theta < x$, $b > 0$, $c > 0$.

The Weibull $R(x)$ distribution reliability function complements the cumulative distribution function to the unity:

$$R(x) = 1 - F(x) \quad (9)$$

The reliability analysis consisted of estimating the Weibull distribution parameters using the most reliable method. The verification of the zero hypothesis that the analyzed variable could be described by the Weibull distribution was performed with the Hollander–Proschan type test at a materiality level of 0.05% [17]. The values of the basic indicators of impurities in the purified effluent discharged to the receiver were analyzed.

Reliability was determined from the cumulative distribution function in graphs, taking into account the normative values of the indicators defined in the Regulation of the Minister of the Environment [21] for effluent discharged from the treatment plant from 15,000 to 99,999 PE: $BOD_5$ – 15 mg $O_2$/L, COD – 125 mg $O_2$/L, general suspension – 35 mg/L, total nitrogen – 15 mg/L, general phosphorus – 2 mg/L [21].

Additionally, an analysis of the correlation between air temperature and the removal effects of individual pollutants was carried out. The null hypothesis was tested:

$$H_0: \rho = 0 \quad (10)$$

equivalent to the lack of interdependence between the variables analyzed, to the alternative hypothesis:

$$H_0: \rho \neq 0 \quad (11)$$

which is about the existence of a relationship between the variables.

For this purpose, a correlation with the Pearson method was used and their statistical significance was confirmed by a *t*-Student test at materiality level $\alpha = 0.05$. Absolute values of the t tests are referred to the critical values read from the tables of the *t*-Student distribution. The correlation factor was found to be statistically significant if: $|t| \geq t\,\alpha_{kr}$.

Multiple regression analysis was performed to estimate the relationship between the effectiveness of the tested parameters as COD, $BOD_5$, TSS, TN, TP and their concentrations at the inflow and outflow to the tested sewage treatment plant. The progressive stepwise method was used to select the independent variables.

## 3. Results and discussion

### 3.1. Quantity of wastewater supplying the treatment plant

#### 3.1.1. Impact of variability in wastewater supply on the effectiveness of treatment

The amount of raw sewage entering the treatment plant varies from day to day. It is very difficult to accurately assess the magnitude of these changes, as they depend on a number of factors, such as the schedule of activities of residents, the style and standard of their living, the season of the year, etc. Variability in the supply of wastewater can be expressed, inter alia, with calculation indicators such as average daily inflow (in a year), average daily (in a month) as well as the minimum and maximum.

A very big problem in treatment plants is the non-uniformity of wastewater supply, and it is practically impossible to coordinate the total amount of wastewater transported from holding tanks. Bugajski et al. [22] in their studies found that the share of accidental waters accounted for between 26.8% and 48.4% of the total amount of wastewater entering the treatment plant, whereas, in incidental cases of intense precipitation, the share of rainwater in the total amount of wastewater in the wastewater system increased to 75%. Comparable results in terms of variability of wastewater supply were obtained by other authors [23], where the average increase in the volume of incoming wastewater relative to the flow of wastewater during the rain-free period ranged from 10.5% (884.9 $m^3$/d) to 69.6% (6153.9 $m^3$/d). The identification of the impact of uneven supply of wastewater on the quality of treatment should indicate how the technological process should be properly implemented.

Based on the obtained results (Fig. 2) it was found that there were very large average daily fluctuations in the amount of wastewater treated throughout the research period (a difference of up to 1,700 $m^3$/d). For the years 2015 to 2019, they were ($m^3$/d) respectively: 3,911 to 4,785; 3,945 to 5,633; 3,805 to 5,278; 3,913 to 4,846; 3,696 to 4,498. However, the annual average arithmetic values over the whole research period exceeded 4,100 $m^3$/d. Similar results were obtained by Chmielowski et al. [24] who claimed that the daily differences were almost three-fold (from 1,469 to 3,788 $m^3$/d).

The wastewater treatment plant is also used for wastewater from rural areas (15 localities), with a total population of 36,501 people (including the town – 27,541 people).

The following components are included in the population of Biłgoraj within the agglomeration of Biłgoraj:

- number of residents and temporary residents of the agglomeration using an existing sewerage network: 35,634 people.
- number of residents and temporary residents in the agglomeration using individual municipal wastewater

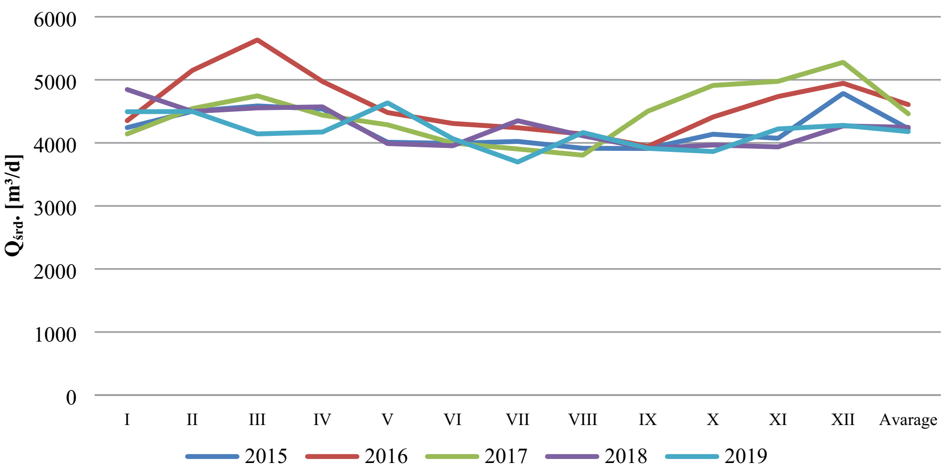



Fig. 2. Quantity of wastewater supplying the analysed treatment plant between 2015 and 2019.

treatment systems (household treatment plants, holding tanks, unplanned for connection to the grid (wastewater transport): 897 people.

According to the Regulation of the Minister of Infrastructure of 14 January 2002 on determining average standards of water consumption [25], in the case of supplying households with installations:

- (rural area) water supply, toilet, bathroom, local water source for buildings connected to the wastewater network, the average water consumption standard per capita is 80–100 L/Res d [24].
- (urban area) water supply, toilet, bathroom, hot water supply to the apartments (from heat and power plant, district or block boiler room at the level of 140–160 L/Res d).

Most of the wastewater comes from the city of Biłgoraj (approx. 75%) and a unit amount of wastewater per capita can be estimated to be 120 L/Res d.

The average daily quantity of industrial wastewater was calculated on the basis of an annual summary of the amount of wastewater, with wastewater production at 5 d/week. Thus, the estimated average daily quantity of industrial wastewater is Qdśr = 320.0 $m^3$/d.

### *3.2. Composition of wastewater treatment*

#### *3.2.1. Quality of raw wastewater*

Wastewater contains chemical impurities (dissolved organic and inorganic compounds), physical (suspensions) and biological (micro-organisms mostly belonging to the bacterial flora living in the human and animal gastrointestinal tract). The main indicators of chemical and physical impurities are TN, TP, COD, $BOD_5$ and TSS. Due to the nature of the wastewater system flowing to the analyzed treatment plant, changes in their quality were also observed with quantitative changes.

The high volatility coefficient of indicators of contaminants entering the treatment plant – at 5.28 for total nitrogen, 4.10 for COD, 2.87 for TSS and 4.10 for $BOD_5$ (Table 1) indicates a high variation in the quality of incoming wastewater according to the scale given by Wawrzynek [26].

On the basis of the results of physical–chemical studies of raw sewage, it was found that the values of pollutant indicators are typical of municipal wastewater, similar to those reported by other authors [26–32].

According to this dependency (3), raw sewage supplying the treatment plant under consideration may be considered to have a rather good susceptibility to biological degradation of organic pollutants, as demonstrated by the average annual COD/$BOD_5$ quotient, which in 84% of the results was below 2.2 (Table 2).

On the other hand, when analyzing the susceptibility of raw sewage to the degradation of biogenic compounds, it is noted that the effluent composition associated with the appropriate ratio between $BOD_5$ and total nitrogen (TN) and $BOD_5$ and general phosphorus (TP) provided adequate conditions for the biological processes of nitrogen removal by denitrification and removal of phosphorus compounds during defosphatation processes (Table 2). According to other authors, the mixing of municipal wastewater and industrial wastewater may have an impact on the biodegradability of wastewater [33].

The analyzed wastewater treatment plant functioned at different concentrations of pollutants in raw sewage. COD ranged from 610 to 2,094 mg $O_2$/L, with an average of 1,082.82 mg $O_2$/L (Table 1). The largest group, that is, 45% were COD concentrations in the range 801–1,000 mg $O_2$/L, 28% consisted of 1,001–1,200 mg $O_2$/L. Recently (1.6%) COD concentrations were recorded in the range 400–600 mg $O_2$/L (Fig. 3).

The content of general suspensions is an important indicator for assessing the quality of wastewater and

Table 1
Composition of raw sewage supplying the treatment plant

| | Average | Median | Min. | Max. | SD | CV |
|---|---|---|---|---|---|---|
| $BOD_5$ (mg $O_2$/L) | 526.83 | 515 | 181 | 960 | 150.01 | 3.51 |
| COD (mg $O_2$/L) | 1,082.82 | 1,001 | 610 | 2,094 | 264.12 | 4.10 |
| TSS (mg/L) | 346.42 | 327 | 48 | 840 | 120.83 | 2.87 |
| TN (mg/L) | 80.64 | 83.3 | 20.1 | 116.3 | 15.27 | 5.28 |
| TP (mg/L) | 10.26 | 10 | 5 | 19.3 | 3 | 3.42 |

Table 2
Ratios between mean values of selected pollution indicators

| Ratio | Recommended value (Heidrich et al. 2008) | Values in the analysed facility | | | | |
|---|---|---|---|---|---|---|
| | | Min. | Max. | Average | %$x$ ≤ recommend value | %$x$ ≥ recommend value |
| COD/$BOD_5$ | ≤2.2 | 1.84 | 2.75 | 2.09 | 83.9% | 16.1% |
| $BOD_5$/TN | ≥4.0 | 4.25 | 9.00 | 6.21 | 0% | 100% |
| $BOD_5$/TP | ≥25 | 42.33 | 59.60 | 50.62 | 0% | 100% |

determining their impact on the water of natural receivers. As shown in Table 1, the level of general suspensions in raw sewage ranged from 48 to 840 mg/L, which represented a significant imbalance throughout the study period. The highest number of results, that is, 37% were TSS values in the range 301–400 mg/L followed by 29% – 201–300 mg/L and 23% 401–500 mg/L. Incidentally, that is, 1.6% were below 100 mg/L (Fig. 4).

A commonly used indicator in monitoring the degree of pollution of municipal wastewater is the $BOD_5$ parameter, which expresses the ability of micro-organisms to degrade organic substances under aerobic conditions during 5 d when biochemical processes are most intense. The average $BOD_5$ value in raw sewage supply to the municipal wastewater treatment plant in question between 2015 and 2019 was 526.83 mg $O_2$/L. The $BOD_5$ value in raw sewage was between 181 and 960 mg $O_2$/L (Table 1). The highest percentages of concentrations were in the range 401–500 and 501–600 mg/L, which accounted for 28% and 29% of the total results respectively (Fig. 5). Another group with values of 13% and 14% were $BOD_5$ concentration ranges of 301–400 and 601–700 mg/L. $BOD_5$ values of 701–800 and above 800 mg/L constituted 5% each. Individual cases lower than 300 mg/L were found (Fig. 5). This indicates a high variability of the said component in raw sewage throughout the research period. This trend shows

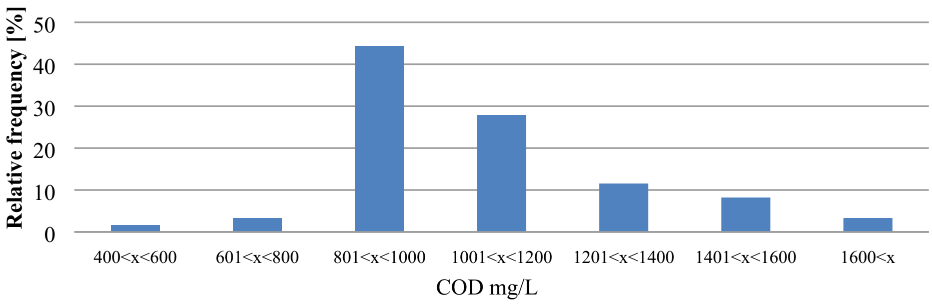



Fig. 3. Histogram of COD distribution in raw sewage.

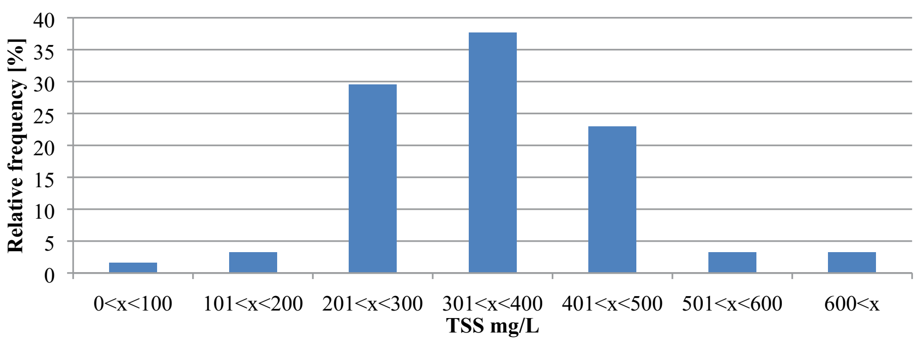



Fig. 4. Histogram of TSS distribution in raw sewage.

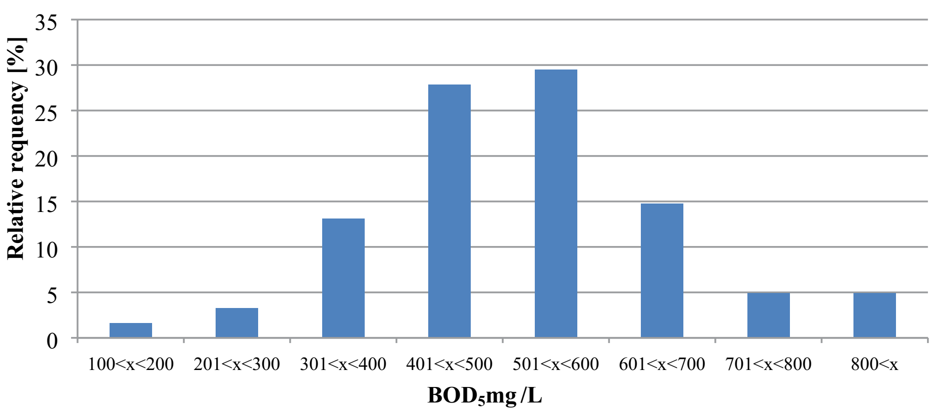



Fig. 5. Histogram of $BOD_5$ distribution in raw sewage.

the inflow of wastewater more and more loaded with organic pollutants. The reason for this may be increased wastewater transport by septic tanker trucks. Such wastewater is rotten and carries a significant load of organic compounds.

Biogenic concentrations ranged from 20.1 to 116.3 mg N/L and 5 ÷ 19.3 mg P/L, with mean values of 80.64 mg N/L and 10.26 mg P/L respectively (Table 1). Low concentrations of total nitrogen in raw sewage may result from periodic inflows of foreign (infiltration and accidental) waters in which the nitrogen charge is very low, whereas above-average high nitrogen values in raw sewage were probably the result of an influx of industrial wastewater [22,34–36]. In raw sewage, the most often reported, that is, 46%, total nitrogen concentrations were in the range of 80.1–95 mg/L. The second group was in the range of 65.1–80 mg/L. Net nitrogen concentrations above 110 mg/L and below 35 mg/L were reported incidentally (Fig. 6).

For total phosphorus concentrations, the largest group, that is, 31% were in the range of 9.1–11 mg/L (Fig. 8.) The next places in terms of quantity ranged from 7.1–9 mg/L – 23% and 11.1–13 mg/L 19%. Of all results, 5% were the lowest values, that is, from 3 to 5 mg/L, while the highest, that is, above 17 mg/L, constituted 3% of the total values obtained (Fig. 7).

The presented results of the studies of raw sewage composition are typical of municipal wastewater analyzed by other authors [22,37–41]. The composition of raw sewage may be influenced by the prevailing weather conditions. In dry seasons, the concentration of pollutants in raw effluents is significantly higher than in the rainy season. The quality of wastewater entering the treatment plant is highly variable depending on the intensity of the precipitation. In addition, a change in the structure of water consumption in the city, and therefore also the quality wastewater parameters, has now caused the treatment plants to operate at a much lower hydraulic load, with a higher load of pollutants.

### *3.3. Pollutant removal efficiency of mechanical wastewater treatment*

Mechanical treatment is intended to prepare wastewater for further technological processes and includes mechanical and physical processes, that is, straining, sedimentation and flotation. As part of the pre-treatment, raw sewage flows consecutively through the following structures and facilities: screens, grit chambers and primary settling tanks. In the analyzed treatment plant, there are two radial primary settling tanks with a diameter of 18 meters each. The efficiency of wastewater treatment in the mechanical stage has a huge impact on the efficiency of the removal of pollutants in the next system, that is, biological.

The average effectiveness of removal of organic compounds, as shown in Table 3, was not very high in the analyzed treatment plant. The efficiency of the $BOD_5$ reduction was in the range of 0%–59.5%, COD 0.89%–59%, TSS 26.9%–76.8%.

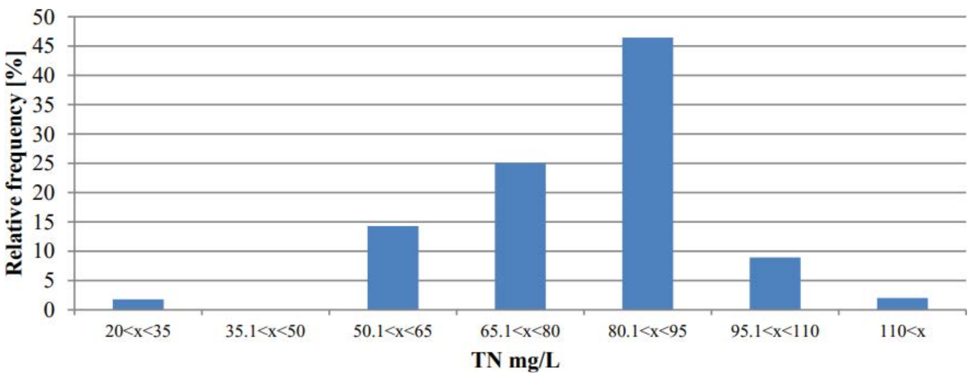



Fig. 6. Histogram of TN distribution in raw sewage.

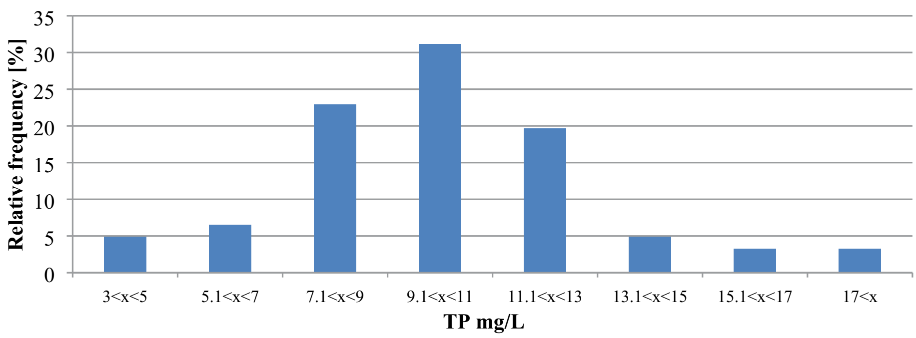



Fig. 7. Histogram of $BOD_5$ distribution in raw sewage.

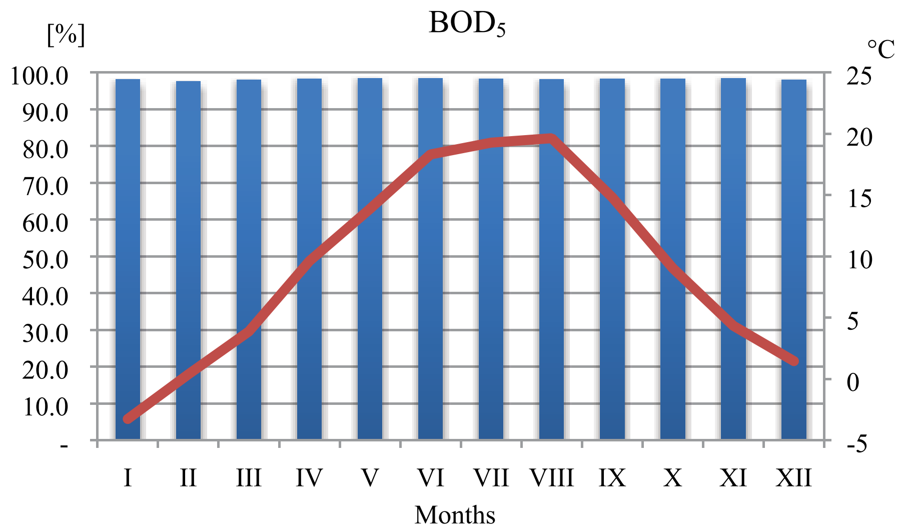



Fig. 8. Average monthly $BOD_5$ reduction efficiency and monthly average air temperature.

Table 3
Pollution removal efficiency in primary settling tanks (%)

| | Average | Median | Min. | Max. | SD | CV |
|---|---|---|---|---|---|---|
| $BOD_5$ | 23.90 | 22.5 | 0 | 59.52 | 13.77 | 0.58 |
| COD | 33.94 | 33.70 | 0.89 | 58.99 | 12.69 | 0.37 |
| TSS | 52.22 | 53.54 | 26.9 | 76.78 | 13.86 | 0.26 |

The average reduction in $BOD_5$, which oscillated at 23.9%, allowed the ratio to decrease from the average level in raw sewage, that is, 526.83 to 409.8 mg $O_2$/L after the primary settling tank (Table 4). The same average $BOD_5$ value was obtained by Nowobilska-Majewska and Bugajski [42] by analyzing wastewater after mechanical treatment in a mechanical–biological wastewater treatment plant. Other scientists were obtained by other researchers [43,44].

Mechanical wastewater treatment resulted in a reduction of COD to an average level of 705.3 mg $O_2$/L (Table 4). The efficiency of reducing this indicator in the analyzed treatment plant throughout the research period was characterized by a high variation, as demonstrated by a high variability ratio of 37%. The TSS content also decreased by more than half, which eventually reached an average of 150.1 mg $O_2$/L (Table 4) over the entire study period. Sher et al. [45] in their studies found average concentrations of impurities in mechanically cleaned wastewater at the level of COD – 233 mg $O_2$/L, TSS – 150 mg/L. For TSS, the authors achieved the same value, however, in the case of COD, in the analyzed treatment plant in Biłgoraj the mean concentration was found to be three times higher (705.3 mg $O_2$/L).

As mechanical purification reduces mainly organic impurities, the effectiveness of reducing biogenic elements at this stage has not been analyzed.

### 3.4. Pollutant removal efficiency in the entire treatment system

The indicator of the efficiency of the entire wastewater treatment process was the degree of reduction in the values of the impurities indicators analyzed. In addition, the effectiveness of the removal of pollutants from wastewater was analyzed in relation to the required quality of wastewater purified in Polish law [21]. The efficiency of wastewater treatment expressed in the purified effluent quality and the percentage reduction of individual pollutant indicators are shown in tabular terms (Table 5) and illustrated in graphs 8, 10, 12, 14, 16.

The variability of incoming wastewater and the variation in the volume of load flowing to the wastewater treatment plant significantly determined the efficiency and stability of the removal of pollutants from wastewater in the biological treatment node. The quality of general wastewater in municipal wastewater treatment plants may lead to the biochemical removal of pollutants [46].

The treatment plant under examination showed a fairly high pollution removal efficiency (Table 5). For organic compounds, that is, $BOD_5$, COD, TSS, their average reduction was over 93%.

The highest efficiency of the treatment plant was achieved at the reduction of $BOD_5$, where the average efficiency of

Table 4
Concentrations of impurities in wastewater after mechanical treatment

| | Average | Median | Min. | Max. | SD | CV |
|---|---|---|---|---|---|---|
| $BOD_5$ (mg $O_2$/L) | 409.8 | 390 | 260 | 640 | 89.2 | 0.218 |
| COD (mg $O_2$/L) | 705.3 | 694 | 402 | 997 | 130.0 | 0.184 |
| TSS (mg/L) | 150.1 | 150 | 87 | 260 | 31.1 | 0.207 |

this process was 98.2% (Table 5). By analyzing the results from each month of the study, the effective operation of the facility can be confirmed in this range (Fig. 8). The lowest $BOD_5$ reduction efficiency was 95.2% and the highest 99.6%. By analyzing the average $BOD_5$ values and their variability throughout the year, it can be concluded that the air temperature did not affect the increase or decrease in system performance (Fig. 8) Moharram et al. [47]. In their studies, they recorded an average $BOD_5$ removal efficiency of 91.6%.

Despite the high effectiveness, an incidental two-fold exceedance of the $BOD_5$ standard (15 mg $O_2$/L) [21] was observed in Poland in December 2018 and February 2019 with results of 16 and 25 mg $O_2$/L, respectively. When considering $BOD_5$ concentrations in wastewater treated in individual months, there is an upward trend of this indicator in colder months (i.e., January to April and then October to December). However, this is not a statistically significant correlation, as shown by the Pearson correlation (Table 6). The largest group, that is, 50% of the total recorded results were concentrations ranging from 5 to 10 mg/L. Another quite numerous set (i.e., 26%) was a range of 10–15 mg/L (Fig. 9).

Multiple regression analysis was performed to estimate the relationship between the effectiveness of the tested parameters as COD, $BOD_5$, TSS, TN, TP and their concentrations at the inflow and outflow to the tested sewage treatment plant. The progressive stepwise method was used to select the independent variables. The statistically significant coefficients ($p < 0.05$) are presented in Table 7.

Linear regression allowed us to conclude that the model with three predictors (inlet COD, outlet COD and outlet $BOD_5$) explains 96% of the variance of the variable efficiency of COD ($R^2 = 0.96$). The model with two predictors (COD inlet and outlet) explains 37% of the variance – efficiency of $BOD_5$ ($R^2 = 0.37$). On the other hand, the model with two predictors (inlet and outlet of TSS) explains 97% of the variance of the variable – efficiency of TSS ($R^2 = 0.97$). The model with three predictors (inlet TSS, inlet and outlet TN) explains 99% of the variance of the variable – efficiency of TN ($R^2 = 0.99$). The model with six predictors (inlet: COD, TSS, TP and outlet: COD, $BOD_5$, TP) explains 97% of the variance of the variable – efficiency of TP ($R^2 = 0.97$). All the obtained models are statistically significant, which was confirmed by the *F* test (*p*-value < 0.05).

Kang et al. [48] when analyzing the same technology found the $BOD_5$ reduction effectiveness at 96.5%, thus achieving in the outflow wastewater values of 8–19 mg $O_2$/L (Table 8).

The stability of the analyzed facility's operating stability is also demonstrated by low values of volatility coefficients for purified wastewater, which were: 0.336 for COD, 0.429 – $BOD_5$, 0.536 – TSS (Table 8).

The proper functioning of the treatment plant was also found on the basis of COD reduction. The average COD removal efficiency was 93.3% (Table 5). Although this value is slightly lower than the $BOD_5$, in the case of COD, no values were found to be above the standard defined in Poland (i.e., 125 mg $O_2$/L) [21]. In Fig. 11 we can notice that higher COD reduction efficiency was observed in months with higher air temperature than in winter months (Fig. 10). At the same time, which is associated with lower air temperatures in these months, higher concentrations of this indicator were recorded at the outflow from the treatment plant. However, when analyzing the correlation between air temperature and efficiency, there was no statistically significant relationship (Table 6).

COD values in outflow wastewater ranged from 20.3–115 mg $O_2$/L to 66.86 mg $O_2$/L (Table 8). These values could be achieved by the treatment plant due to high efficiency of 86.5%–97.9% (Table 5). In purified outflow wastewater from the analyzed treatment plant, most often, that is, 37% of all results were COD concentrations in the range 50–70 mg/L and 70–110 mg/L 26% (Fig. 11). During the whole study period, the maximum value was 115 mg $O_2$/L. Similar values were

Table 5
Pollution removal efficiency throughout the treatment system (%)

| | Average | Median | Min. | Max. | SD | CV |
|---|---|---|---|---|---|---|
| $BOD_5$ | 98.2 | 98.4 | 95.2 | 99.6 | 0.805 | 0.008 |
| COD | 93.3 | 93.6 | 86.5 | 97.9 | 2.412 | 0.026 |
| TSS | 95.4 | 95.9 | 84.5 | 99.8 | 2.880 | 0.030 |
| TN | 82.1 | 83.8 | 43.1 | 89.1 | 8.043 | 0.098 |
| TP | 88.3 | 88.9 | 61.7 | 97.4 | 6.363 | 0.072 |

Table 6
Relationship between air temperature and pollution removal efficiency in the analysed treatment plant $n = 60$

| | Pearson coefficient of correlation | Coefficient of determination | Arithmetic mean | Standard deviation | Value of the importance test | Critical value of the test (significance level $\alpha = 0.05$) |
|---|---|---|---|---|---|---|
| | $R(X,Y)$ | $R^2$ | SR | S | t | $t\,\alpha_{kr}$ |
| Correlation between temperature and pollution removal efficiency | | | | | | |
| Air temp. | – | – | 9.3 | 7.83 | – | |
| $BOD_5$ | 0.182 | 0.033 | 98.2 | 0.80 | 0.5397 | |
| COD | 0.448 | 0.201 | 93.6 | 2.41 | 0.0986 | |
| TSS | 0.390 | 0.152 | 95.4 | 2.88 | –1.1800 | 2.0003 |
| TN | 0.002 | 5.551 | 82.0 | 8.04 | –1.3148 | |
| TP | 0.352 | 0.124 | 88.3 | 6.36 | –0.5309 | |

*Symbols*: stat – value of the test statistic; *p* – importance level of the test; when $p \leq 0.05$ the distribution of data is not Weibull distribution

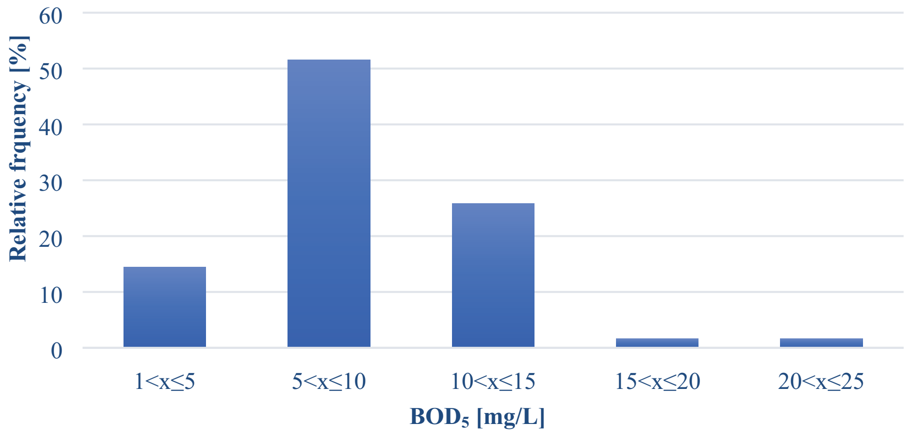



Fig. 9. Histogram of $BOD_5$ distribution in outflow.

Table 7

| Predictions | | Efficiency (%) | | | | |
|---|---|---|---|---|---|---|
| | | COD | $BOD_5$ | TSS | TN | TP |
| Inflow (mg/L) | COD | 0.005 | 0.001 | | | 0.002 |
| | $BOD_5$ | | | | | |
| | TSS | | | 0.011 | –0.004 | –0.003 |
| | TN | | | | 0.206 | |
| | TP | | | | | 0.913 |
| Outflow (mg/L) | COD | –0.090 | –0.019 | | | –0.057 |
| | $BOD_5$ | –0.049 | | | | 0.204 |
| | TSS | | | –0.291 | | |
| | TN | | | | –1.112 | |
| | TP | | | | | –8.923 |
| Improved determination coefficient $R^2$ | | 0.96 | 0.37 | 0.97 | 0.99 | 0.97 |
| Significance of the model (*p*-value for test *F*) | | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 |

Table 8
Concentrations of impurities in wastewater from the analysed treatment plant (mg/L)

| | Regulation (2019) | Average | Median | Min. | Max. | SD | CV |
|---|---|---|---|---|---|---|---|
| $BOD_5$ | 15 | 9.04 | 9.00 | 1.80 | 25.00 | 3.88 | 0.429 |
| COD | 125 | 66.86 | 66.50 | 20.30 | 115.00 | 22.47 | 0.336 |
| TSS | 35 | 14.59 | 14.00 | 1.90 | 39.00 | 7.83 | 0.536 |
| TN | 15 | 15.22 | 13.80 | 8.30 | 84.30 | 11.01 | 0.723 |
| TP | 2 | 1.22 | 1.18 | 0.19 | 4.60 | 0.74 | 0.607 |

recorded by Kang et al. [48] achieving an average removal efficiency of 93.7%. The same authors in purified effluent recorded COD values in the range of 40–70 mg/L. Moharram et al. [47] in their studies found an average COD removal efficiency of 92.6%, while Rong et al. [49] – 81.5%, Yu et al. [50] – 82.6%. Gallardo-Altamirano et al. [51] while Manav Demir and Demir [52] in their research into the analysis of A2/O systems in the event of COD elimination achieved an efficiency of 84%–88%.

The effectiveness of removal of the total suspension was in the range of 84.5% – 99.8% and in the purified effluent its concentration was 1.9 – 39.0 mg/L (Table 5, Fig. 12). Moharram et al. [47], in their studies, recorded an average TSS removal efficiency of 91.6%. A not much higher value, that is, 93% was achieved by Manav Demir and Demir [52]. During five years of observation, an incidental breach of the standard in Poland, that is, 35 mg/L, was observed in the analyzed system in outflow wastewater [21]. The total

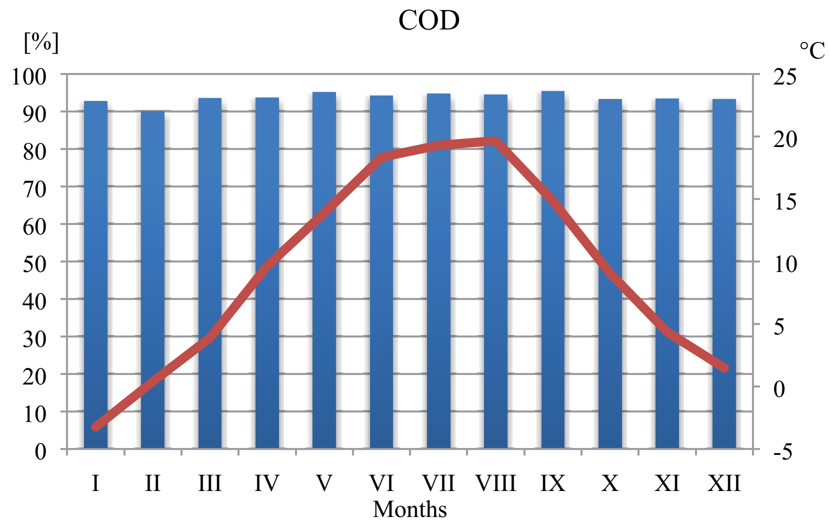



Fig. 10. Average monthly COD reduction efficiency and monthly average air temperature.

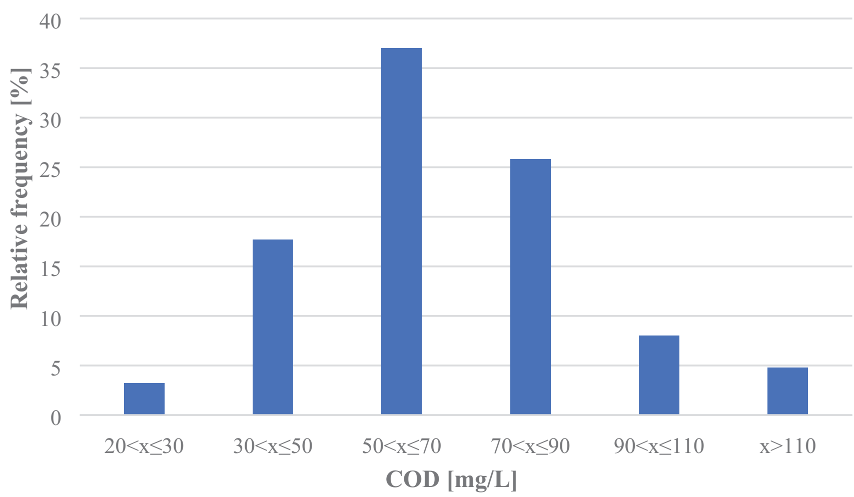



Fig. 11. Histogram of COD distribution in outflow.

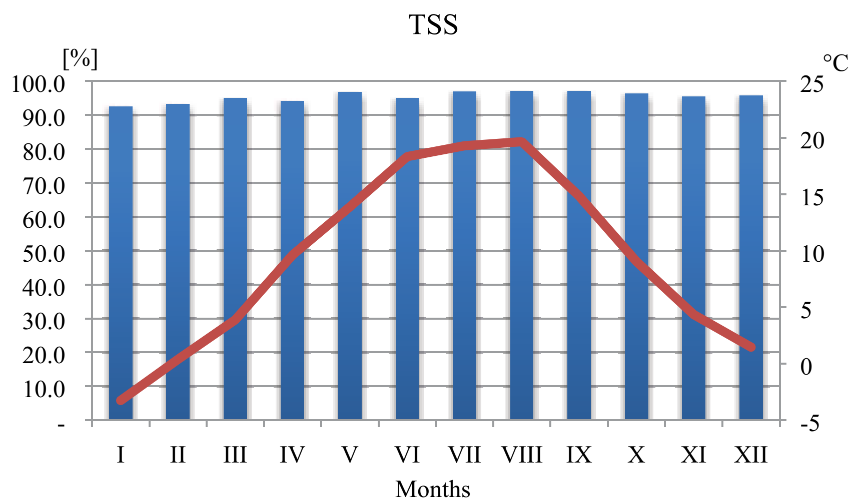



Fig. 12. Average monthly TSS reduction efficiency and monthly average air temperature.

suspension exceeded the maximum limit of 39 mg/L once in February 2019 (Table 5). The values of the test indicator maintain a stable level in purified wastewater. The only sudden increase occurred in the winter of 2019 due to a sudden drop in temperature. In most cases, that is, 41% and 37% of TSS concentrations were reported in the range 10–20 and 1–10 mg/L, respectively (Fig. 13).

Lower mechanical and biological efficiency of the treatment plant was observed with TN removal, which was observed in the range 43.1% – 89.1% and on average 82.1% with the required minimum reduction rate of 85% (Table 5, Fig. 14). In studies by other authors carried out in facilities with the same technological layout, the removal efficiency of TN ranged from 63.9%–71% [53–56]. You et al. [50] achieved an average TN reduction of 57.1%.

The low efficiency of total nitrogen reduction in the analyzed facility reflects the observed exceedances of 15 mg/L (Regulation 2019) in February (53.4 mg/L) and in March 2019 (28.2 mg/L) and in March 2017 where the highest result was observed in the whole study period, that is, 84.3 mg/L (Table 8). Such high concentrations were due to a sharp and sharp decrease in nitrification activity. In addition to the incidental increase in concentrations, the overall nitrogen index present in purified effluents maintains a balanced activity rate in most cases, that is, 70% were reported in the range of 12–16 mg/L (Fig. 15). Cao et al. [54] in their studies, also noted a decrease in the efficiency of TN removal in the winter months to 4.3% in systems using A2/O. Li et al. [57] discussed extensively the effects of temperature on the activity of nitrification bacteria. According to them, the inactivation of the activity of these microorganisms has a clear effect on the fall in temperature. This is also evidenced by the results of Park et al. [58] who found the effectiveness of the removal of TN in the A2/O system in winter at 52.0% and in the summer period 76%.

In the used wastewater treatment technology, that is, A2/O, a very important factor is the internal recirculation of the activated sludge. It allows the supply of nitrates necessary for the purification processes taking place, it should be assumed that nitrification and denitrification processes are more effective in delivering more bacteria and nitrates to the distribution chamber. The main source of nitrates that are denitrified was the internal recirculation of wastewater from the aeration chamber in

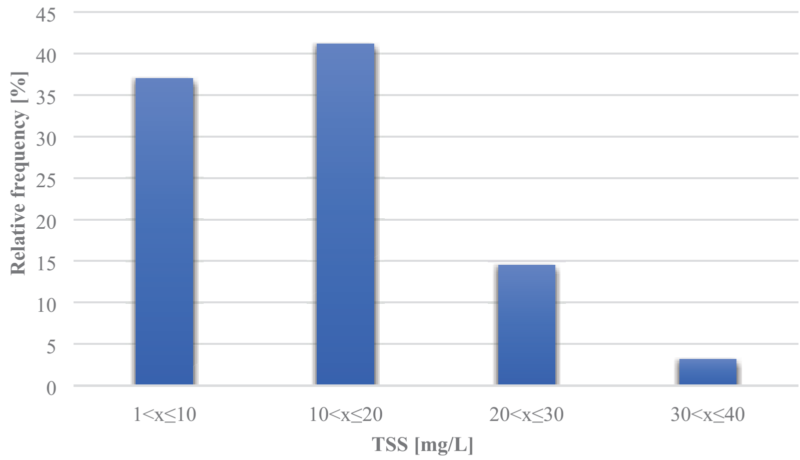



Fig. 13. Histogram of TSS distribution in outflow.

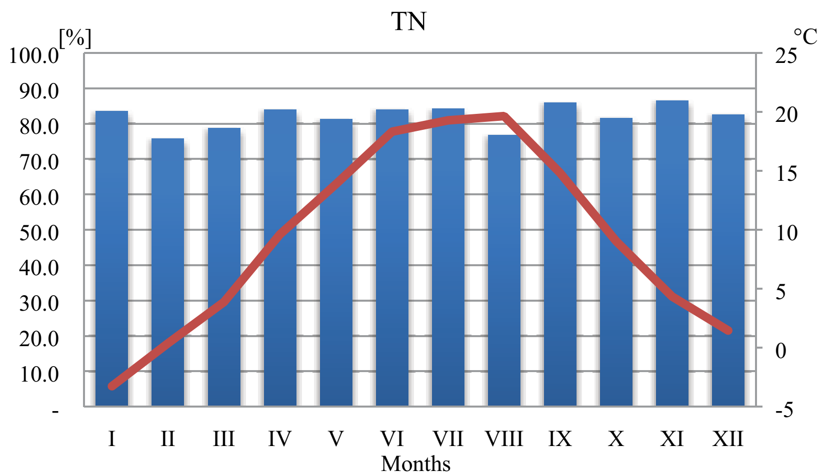



Fig. 14. Monthly average TN reduction efficiency and monthly average air temperature.

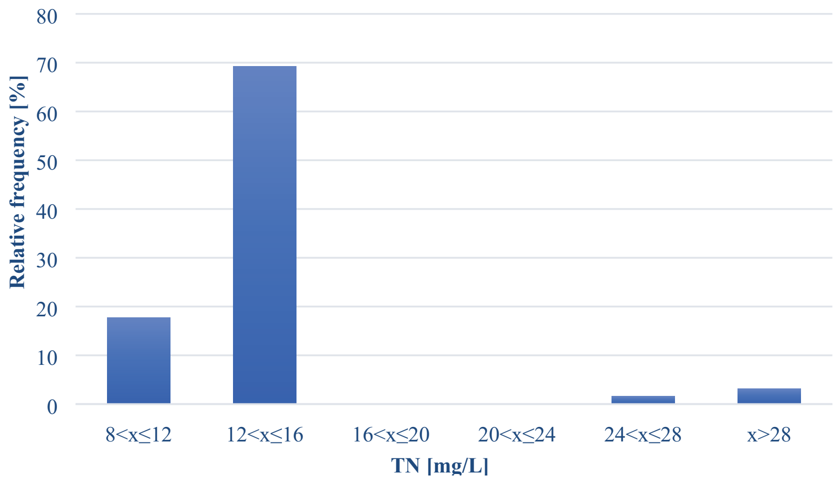



Fig. 15. Histogram of TN distribution in outflow.

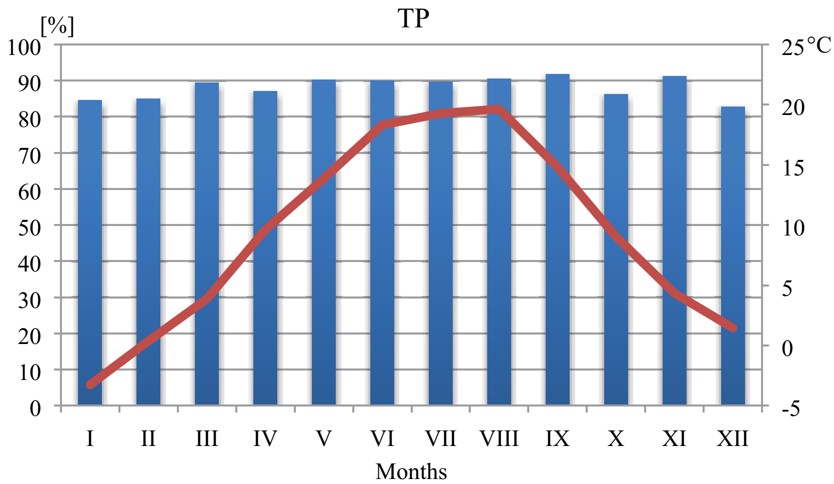



Fig. 16. Average monthly TP reduction efficiency and monthly average air temperature.

the treatment plant. Pre-denitration requires a very large amount of wastewater recirculation to bring nitrates to the denitrification chamber, but the increased amount of denitrification aggravates defosphatation [59]. The optional heterotrophic bacteria of the active sediment under anoxic conditions in the presence of a source of carbon (raw sewage) conduct nitrate respiration (decrease of nitrates) and this protects a larger portion of nitrates supplied by increased sludge recirculation, however, provided that oxygen dissolved in the reactor's distribution chamber is maintained up to 0.5 mg $O_2$/L [60].

The efficiency of removing general phosphorus in the analysed facility was quite high, that is, 88.3%. Individual results ranged from 61.7% to 97.4% (Table 5, Fig. 16). On this basis, it can be concluded that more than half of the total phosphorus from the wastewater has been removed. Kwon et al. [61] found a 70% phosphorus removal efficiency in the facility using A2/O technology. Moharram et al. [47] in their studies recorded the effectiveness of the reduction of TP from 49.6% to 64.9% and a maximum of 83.9%. Reports from other authors indicate the elimination of phosphorus in A2/O systems at 93.6% [49]. Yu et al. [50] determined the effectiveness of TP throughout the system at 76.5%.

However, despite satisfactory efficiency over 5 y, there were two cases of exceedance of the standard for general phosphorus of 2 mg/L [21]. This occurred in September 2015, reaching 4.6 mg/L and in February 2019–2.9 mg/L (Table 8). Since the beginning of 2017, there has been a gradual decrease in the amount of total phosphorus in purified wastewater, only with increases in winter periods. The most common (i.e., 27%) purified effluent was in the range of 1.0–2.5 mg/L (Fig. 17). Phosphorus compounds in the analyzed facility are removed from the wastewater by applying the coagulant PIX at the end of the biological wastewater treatment chambers. The coagulant is dosed by the MaxROY Milton Roy membrane pump in a quantity dependent on the content of phosphorus compounds, whose concentration is measured directly by the local laboratory.

By analyzing the results of the research, it can be concluded that the efficiency of the treatment plant is very similar to other such facilities operating in the world. Zhang

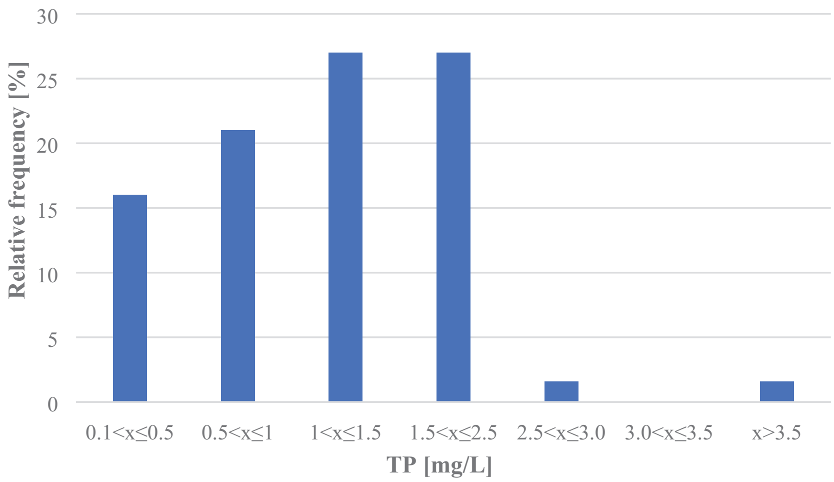



Fig. 17. Histogram of TP distribution in outflow.

et al. [12] noted in their studies the effectiveness of reducing pollution in the same technology at the level of: $BOD_5$ – 97%, COD – 93.3%, TN – 71.7%, TP – 90.7%.

The statistical analysis showed that the efficiency of removing all pollutants from wastewater during the period considered remained stable. At the same time, analysis of the results indicates that the efficiency of the treatment plant is comparable to that of other objects, similar in terms of technology (multi-phase activated sludge) [47–52,56,58].

### *3.5. Assessment of the reliability of the treatment plant*

An ancillary criterion for assessing the efficiency of wastewater treatment is also the reliability of the treatment plant with regard to obtaining the required outflow quality relative to the permit. Reliability calculations are based on the reliability factor calculated using the Weibula statistical method. Authors Andraka and Dzienis [62], when developing guidelines for this wastewater treatment plant at different values of PE, estimated the number of days during which the treatment plant could fail. According to the above, there may be exceedances of the permissible standards at the manufacturer's risk of $\alpha = 0.05$ for 22 d throughout the year in service systems >50,000 PE. The results of the distribution matching with the Hollander–Proschan test together with the estimated parameters are shown in Table 9.

The results of a reliable analysis based on the Weibull method for $BOD_5$ in purified effluent are shown in Fig. 18. On the basis of the analysis obtained, it can be seen that 7% of the samples analyzed contained a value above the acceptable standard, that is, 40 mg/L [21]. This means that 25 d were recorded throughout the year, with excessive amounts of organic carbon expressed as $BOD_5$ and thus exceeding the acceptable standard (40 mg/L). By adopting the guidelines proposed by Andraka and Dzienis [62], it can be concluded that the analyzed treatment plant does not work with high efficiency according to the requirements of the authors.

By analyzing the Weibull method, the reliability of disposing of the total suspension in the analyzed treatment plant was found to be high with an efficiency of 99%. The comparison with the fairness limit values shows that the reliability of removal of the general suspension during the period considered was 9.1% higher than the required one, that is, 89.9% [62]. This means that only 3 d during a 1-y period of time are likely to have outflow effluent with increased total suspension. The difference between the number of exceedances for TSS and the permissible number of days on which the object is not functioning properly, at $\alpha = 0.05$, was 19 d/y. It can therefore be concluded that the facility works with high efficiency when it comes to removing TSS from wastewater.

In the case of COD in purified effluents on the basis of Weibull's reliability analysis, no values higher than the limit value were found, which means that the analyzed treatment plant works 100% reliably throughout the year (Fig. 18). During the whole test period, not a single value was found to be higher than the acceptable value, that is, 125 mg/L. It can be said that the treatment plant for 365 d a year in case of COD removal works reliably. The comparison with the fairness limit values shows that the reliability of COD reductions over the period considered was 6.3% higher than the required ones, that is, 93.7%.

Notation: dashed red line – reliability function, dashed black line – the probability of achieving the indicators limit in the effluent [21].

On the basis of the cumulative distribution function in Fig. 18, it is concluded that 44% of the purified effluent samples have exceeded the total nitrogen limit of 15 mg/L. Therefore, in the effluent discharged to the receiver from the treatment plant, on approximately 160 d during a year there are values above the limit for total nitrogen concentrations. Authors Andraka and Dzienis [62], when developing guidelines for facilities handling more than 50,000 PE, estimated the number of days during which improper treatment plant operation is possible. According to the above, the systems may exceed the acceptable standards for 22 d throughout the year at the manufacturer's risk of $\alpha = 0.05$. On this basis, it can be concluded that the treatment plant under examination does not comply with the requirements of the Regulation for almost half of the year. This is the result of the instability of nitrification and denitrification

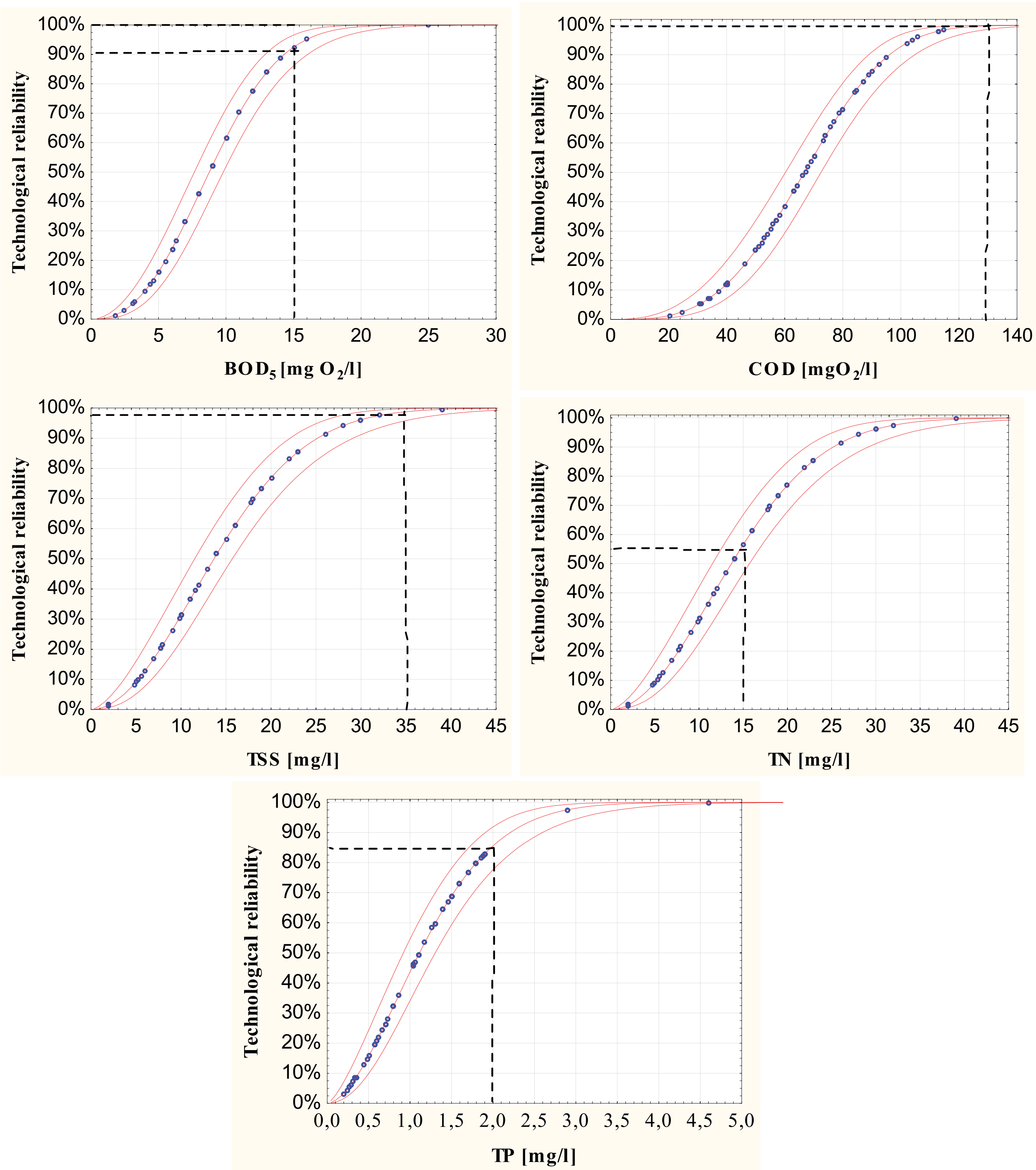



Fig. 18. Weibull cumulative distribution functions and the technological reliabilities determined for each pollution parameter. *Notation*: dashed red line – reliability function; dashed black line – probability of achieving the indicators limit in the effluent (Regulation 2019).

processes, which are responsible for the removal of nitrogen compounds in a biological reactor. Disruption of the biological reactor may be caused by a too short time of individual operating cycles, periodic impacts are greater than expected in the design of general nitrogen charges in the wastewater supply to the treatment plant and cooling of wastewater in biological reactors as a result of the effects of atmospheric temperature in winter. An equally important aspect influencing the increased effectiveness of nitrification and denitrification processes is the constant control

Table 9
Parameters of the Weibull distribution and the Hollander–Proschan goodness-of-fit test

| Parameter | Parameters of Weibull distribution | | | Hollander–Proschan goodness-of-fit test | |
|---|---|---|---|---|---|
| | Location | Shape | Scale | stat | *p* |
| $BOD_5$ | 0.0222 | 2.4495 | 10.176 | 0.0033 | 0.9973 |
| COD | 3.4848 | 3.2972 | 74.582 | 0.0849 | 0.9323 |
| TSS | 0.2000 | 1.9661 | 16.464 | 0.0541 | 0.9568 |
| Total nitrogen | 8.0909 | 1.6644 | 17.214 | 0.2046 | 0.8378 |
| Total phosphorus | 1.2525 | 1.7532 | 1.3727 | –0.0547 | 0.9564 |

*Symbols*: stat – value of the test statistic; $p$ – importance level of the test; when $p \leq 0.05$ the distribution of data is not Weibull distribution

of the ratio of organic carbon expressed in $BOD_5$ to total nitrogen in the wastewater supply to the biological reactor. Where this dependence is lower than required, wastewater with increased organic carbon value should be periodically dosed, which is the source of energy for the active sediment micro-organisms.

For total phosphorus concentrations in purified effluents, the limit value of 2 mg/L was exceeded in 15% of cases, as shown in Fig. 4. Therefore, the limit values for total phosphorus concentrations are exceeded by approximately 55 d/y. In adopting the guidelines proposed by Andraka and Dzienis [62] according to which this treatment plant should operate with a reliability of at least 93.7% at manufacturer's risk of $\alpha = 0.05$, improper operation of a treatment plant with PE of more than 50,000 for 22 d/y is permitted. In the case of the treatment plant under consideration, the reliability of the removal of general phosphorus on 55 d/y is reduced, thus the values obtained during these days are at a level that does not meet the reliability requirements.

## 4. Conclusion

In order to allow for the periodic retention of excess wastewater or the collection of wastewater with parameters not allowing their direct entry into the biological part of the treatment plant, a retention-averaging tank should be used. This would allow for automatic portioning and protection against the destruction of activated sludge.

The results of the studies indicate that the wastewater treatment process can be made more effective by applying additional internal recirculation of the mixture of wastewater and sludge from the final part of the oxygen zone to the anoxic zone. This will provide the necessary amount of nitrates for the treatment process underway.

The results of the Weibull-based reliability analysis showed the high performance of the system in the case of TSS and COD reductions. In the case of the treatment plant under consideration, the reliability of the removal of general phosphorus in 55 d/y is reduced, thus the values obtained during these days are at a level that does not meet the reliability requirements. At the same time, the treatment plant under examination does not meet the requirements of the TN elimination regulation for almost half of the year. The cause of this condition is the instability of nitrification and denitrification processes, which are responsible for the removal of nitrogen compounds in a biological reactor.

In order to further analyze the technological process of wastewater treatment, physicochemical examinations of wastewater after biological treatment should be carried out. This would make it possible to better diagnose and prevent possible post-treatment excesses of pollutants.

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