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Technological reliability of sewage treatment plant with the Pomiltek Mann type bioreactor

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Abstract

The aim of the work was to determine the technological reliability of the selected pollution indicators removal BOD_5, COD_{Cr} and total suspension from the sewage treatment plant working with the bioreactor Pomiltek Mann type. Wastewater treatment plant which is a subject of this study is located in Lesser Poland, in Siepraw commune. The analysis was performed using the Weibull method for basic indicators of impurities, BOD_5, COD_{Cr} and total suspended solids. Physicochemical analyses of raw and treated wastewater, were carried out in the period from 2003 to 2014 (11 years). The research period included measured values of pollutions indicators in 38 samples of raw and treated sewage. For each of pollution indicators descriptive statistic, percentage reduction (η) and treatment plant reliability factors (RF) were calculated. Average reduction for BOD_5 and TSS was on level equal 94%, only for COD the average reduction was lower and was on level 89%. The reliability values determined by Weibull method, were: 75% (BOD_5), 90% (COD_{Cr}) and 89.5% (TSS). The reliability results have been lower than the presented by literature source, which means that work of wastewater treatment plant in Siepraw was not satisfied in 11 years of research.

Key words: *pollution indicators, technological reliability, wastewater treatment plant, Weibull method*

INTRODUCTION

Water is the main component of the sewage (over 98%). The rest of it is dirty wastes in almost every kind of forms which are produced and discharge by human. In Poland for the last few years we can observe the dynamic development of water supply system in city and village areas what contributes to the discharge of the larger amount of sewage [MŁYŃSKI *et al*. 2019]. Unfortunately for many years till now in Poland has been a large disproportion in sanitation service between rural and urban areas. The dispersed land developments in rural areas are the primary problem to creation of collective sewage system [JUCHERSKI *et al*. 2019; WIERZBICKI 2006]. Moreover the lack of sense of social and ecological responsibility and desire to save on the cost of emptying a sewage tank it still of the reasons to illegal draining of sewage to the soil or stream [JÓŹWIAKOWSKI *et al*. 2018]. This kind of problem exist also in the other Central and Eastern European countries. According to prognoses, around 80% of pulation in rural areas in Central and Eastern Europe are not connected to sewage treatment system [PIASECKI 2019].

The sewage as a composition of water, organic and mineral compounds are biochemical degradable. The effect of biochemical transformation, determine the qualities composition of sewage outflow. Furthermore, sewage contains large group of microscopic organisms mostly bacteria which can be very danger for our healthy. In order to protect environmental of negative impact of sewage receives, it is very important to control quality of treated process [BUGAJSKI *et al*. 2015; PAWEŁEK, BUGAJSKI 2017]. Negative impact of sewage depends on type of the discharge for example whether it is amount of suspended solids or organic matter or hazardous pollutants like heavy metals and organo chlorines. High levels of soluble organics may cause oxygen depletion with a negative effect on aquatic biota. Contamination of the coastal water may result in changes in nutrient levels, abundance, biomass and diversity of organisms, bioaccumulation of organic and inorganic compounds and alteration of trophic interaction among species [SUBRAMANI *et al*. 2014]. One of the commonly used methods to control the remove pollutants from wastewater is to compare the concentration of pollution indicators in outflow to the permissible values in legal acts for the sewage treatment plants. Mathematical method which is very simple and popular is based on calculated the reduction coefficient between pollutants concentration in inflow and outflow [BUGAJSKI, KACZOR 2008; BUGAJSKI, MIELENZ 2008; BUGAJSKI, WAŁĘGA 2010; CHMIELOWSKI *et al*. 2009; KACZOR, BUGAJSKI 2007]. Moreover, to assess wastewater treatment plant can be also use indicators of treatment efficiency such as: technological reliability coefficient (*RF*), technological efficiency index (P_{sw}) and coefficient of risk of negative operation of wastewater treatment plant (R_s). The stability assess of the wastewater treatment plant can be described based on the control card X and card control CUSUM. Both of the methods in simple way can showed an unstable operation periods of wastewater treatment plant [GÓRKA 2015; KRZANOWSKI, WAŁĘGA 2006; MIERNIK, MŁYŃSKI 2014; MŁYŃSKI *et al*. 2016]. Assessment of pollution indicators removal reliability it is still a new and interesting issue. To predict reliability process of removal pollution by wastewater treatment plant can be use Weibull method. The reliability is the main aspect of quality, and allow to specify the time without failure or disruptions during of wastewater treatment process [BUGAJSKI 2014]. All of described methods are aimed to controlling the effectiveness of wastewater treatment plant work, and allow to detect irregularities during the process. Quickly localization the issue enables the making changes and allows to eliminate it in the future.

The aim of the study is to assess the reliability of organic pollutants removal expressed in BOD_5, COD_{Cr} and total suspended solids in wastewater treatment plant with the Pomiltek Mann type bioreactor.

MATERIALS AND METHODS

RESEARCH AREA AND SEWAGE TREATMENT PLANT

The sewage treatment plant is located in Lesser Poland voivodeship, in Siepraw commune. The location of the object in Siepraw was presented in Figure 1.

The sanitary system is divided into two water catchment areas (Siepraw and Dobczyce). The first one has length around 70 km with 7 pumping stations, and includes a few areas: Siepraw, Łyczanka, Czechówka and part of Zakliczyn. The second one includes Dobczyce and Zakliczyn areas, and it has length around 20 km with 16 pumping stations. The actual number of inhabitants in Siepraw community is 8 852, of which 60% are connected to sewerage system. The rest of inhabitants (40%) still discharge sewage to septic tanks, from which a special car transport it to sewage treatment plant [Gmina Siepraw undated].

Sewage treatment plant type Pomiltek Mann in Siepraw was produced as a Finnish technology. Object working in this technology is based on three general processes: mechanical, biological and chemical. The organic matter had been decomposed as a result of processes carried out by activated sludge microorganisms (biochemical degradation of organic compounds) by using three-phase nitrifying activated sludge with separated additional sludge oxygen stabilization. Based on the information from Commune Office in Siepraw it was founded that the rainwater is 10% of total amount of wastewater. According to this the projected capacity of the treatment plant is $Q_{avg} = 300\ m^3 \cdot d^{-1}$, and it's population equivalent (PE), determined on the basis of the BOD_5 load, is 1500. Simplified technological scheme of sewage treatment plant in Siepraw is presented in Figure 2.

According to the Polish obligatory standard [Rozporządzenie… 2014], for the wastewater treatment plant with over 1500 population equivalent, the probable value of biochemical oxygen demand (BOD_5) in treated sewage is 40 mg $O_2 \cdot dm^{-3}$, chemical oxygen demand the dichromate

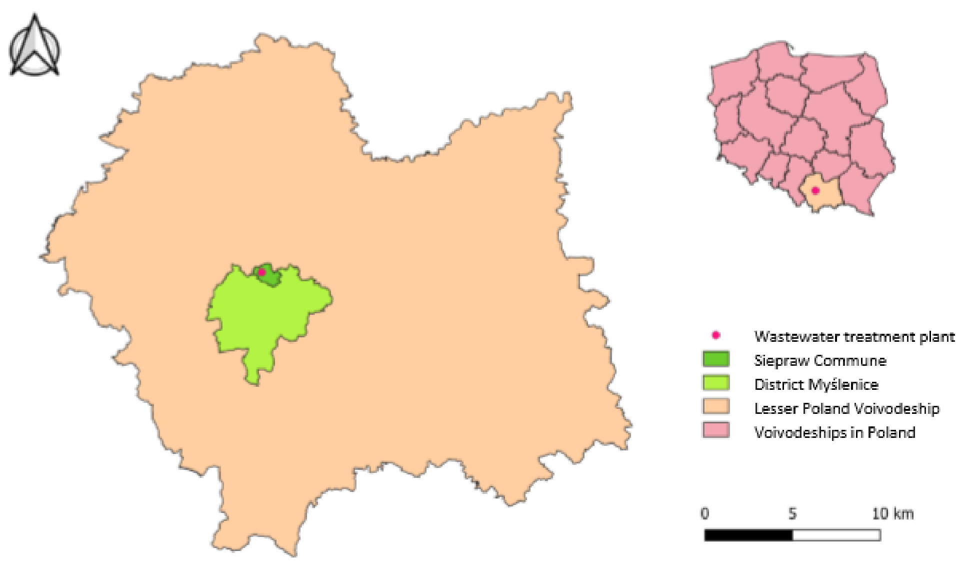


Fig. 1. Location of sewage treatment plant in the background of the Siepraw commune; source: own elaboration

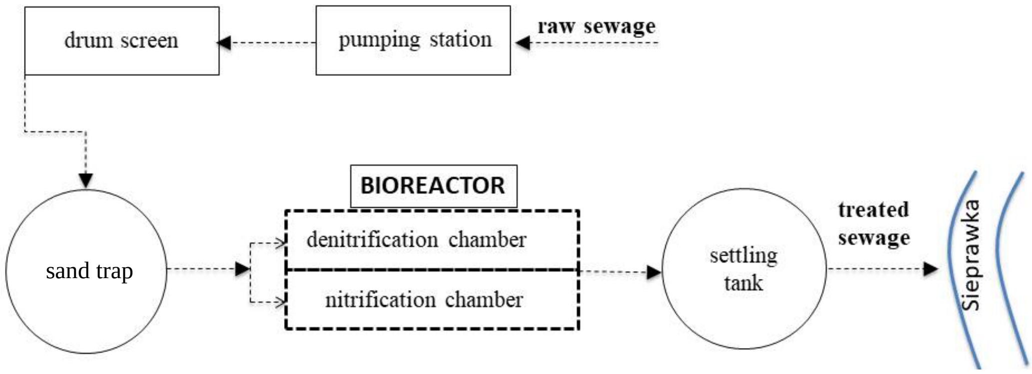


Fig. 2. Simplified technological scheme of sewage treatment plant in Siepraw; source: own elaboration

method (COD_{Cr}) – 150 mg O_2·dm^{-3}, total suspended solids (TSS) – 50 mg·dm^{-3}. Moreover, the Regulation of the Minister for Environment determines the minimum amount of the collected sewage samples after treatment process per year. In this case for this type of sewage treatment plant with equivalent number of inhabitants – $ENI \leq 2\,000$ there are four control sewage samples per year.

RESEARCH METHODS

The analysis was made based on values of following pollution indicators in raw and treated sewage: BOD_5, COD_{Cr}, TSS. The results of physic-chemical analysis include 11 years period (from 2003 to 2014). The research period included measured values of pollutions indicators in 38 samples of raw and treated sewage, in each. The first part of analysis of the pollution indicators series includes the calculation of the descriptive statistics. Besides minimum (min.), mean (mean), maximum (max.) values and the measures of dispersion such as: standard deviation (SD) and coefficient of variation (C_v) were calculated. Furthermore, based on the noted of organic compounds (BOD_5 and COD_{Cr}) values in inflow wastewater on the sewage treatment plant, the evaluation of the sewage biodegradability was performed. For this purpose, the annual averages of COD_{Cr} and BOD_5, was calculated and then, ratio between them was determined. In according with the guidelines presented by literature sources, susceptibility of sewage to the biological transformation process was determined as [MIKSCH, SIKORA 2010; MŁYŃSKA *et al*. 2017]:

$\frac{COD_{Cr}}{BOD_5} < 2.0$ – easy biodegradability

$\frac{COD_{Cr}}{BOD_5} = 2.0–2.5$ – medium biodegradability

$\frac{COD_{Cr}}{BOD_5} = 2.5–5.0$ – weak biodegradability

$\frac{COD_{Cr}}{BOD_5} > 5.0$ – non degradable matter

In the work for sewage treatment plant was calculated the value of the two coefficients: reduction factor and reliability factor. The reduction coefficient was calculated given by CHMIELOWSKI *et al*. [2016]:

$$\eta = \frac{C_s - C_0}{C_s} \cdot 100\% \tag{1}$$

Where: C_s = the average concentration of a pollution indicator in the raw sewage (mg·dm^{-3}), C_0 = the average concentration of a pollution indicator in the treated sewage (mg·dm^{-3}).

The treatment plant reliability factor (RF) was calculated as the quotient of the average concentration of and individual pollution indicators in the treated sewage and its permissible values in treated wastewater. The reliability factor is defined as [MIERNIK, WAŁĘGA 2006; MŁYŃSKI *et al*. 2016]:

$$RF = \frac{\bar{x}}{x_{per}} 100\% \tag{2}$$

Where: x = the average concentration of a pollution indicator in the outflow wastewater (mg·dm^{-3}), x_{per} = the permissible concentration of a pollutant indicator in the outflow wastewater (mg·dm^{-3}).

In the second part of analysis, the efficiency of BOD_5, COD_{Cr} and TSS removal were determined using the Weibull reliability theory. The assumed permissible value of the analysed parameters represent the Polish standards for the pollution concentration limited value in treated sewage, for this kind of object (1 500 PE). The reliability of the sewage treatment plant was determined by Weibull method. The Weibull distribution is characterized by the probability density function with three mainly parameters b, c and θ [JÓŹWIAKOWSKI *et al*. 2017; JÓŹWIAKOWSKI *et al*. 2018]:

$$f(x) = \frac{c}{b}\left(\frac{x-\theta}{b}\right)^{(c-1)} e^{-\left(\frac{x-\theta}{b}\right)^{c}} \tag{3}$$

Where: x = variable defining the concentration of given contamination indicator in treated sewage, b = scale parameter, c = shape parameter, θ = location parameter.

It is assumed that $\theta < x$, $b > 0$, $c > 0$.

The Weibull distribution parameters were estimated by the maximum likelihood method. The quality if the Weibull distribution to empirical data was assessed by Hollander–Proschan test. All results were initially analysed by Statistica software. The reliability analysis of effectiveness operation of the sewage treatment plant was analysed with regard to the following parameters BOD_5, COD_{Cr} and TSS. The Weibull method can be used for the approximation of empirical data was verified for the estimated distributions. Results of the statistical analyses of reliability p for all pollution indicators shown that the empirical data can be described with the Weibull distribution.

RESULTS AND DISCUSSION

At the first part of analysis, the value of the descriptive statistic for pollution indicators observational series were determined and presented in Table 1. In Figure 3 is shown the ratio between COD_{Cr} and BOD_5 in raw sewage and after treated process.

Table 1. The values of descriptive statistics for pollutants indicators in sewage from wastewater treatment plant in Siepraw

Pollution indicator	Unit	Raw sewage				
		min.	mean	max	*SD*	C_v
BOD_5	mg $O_2 \cdot dm^{-3}$	100.0	543.8	2200.0	347.2	0.64
COD_{Cr}	mg $O_2 \cdot dm^{-3}$	268.0	1228.1	6117.0	1060.4	0.86
TSS	mg$\cdot dm^{-3}$	120.0	579.9	2958.0	572.4	0.99
		Treated sewage				
BOD_5	mg $O_2 \cdot dm^{-3}$	2.7	28.5	103.0	21.8	0.76
COD_{Cr}	mg $O_2 \cdot dm^{-3}$	25.5	86.6	225.0	45.1	0.52
TSS	mg$\cdot dm^{-3}$	3.2	25.0	106.0	21.6	0.86

Explanations: *SD* = standard deviation; C_v = coefficient of variation, BOD_5 = biochemical oxygen demand, COD_{Cr} = chemical oxygen demand the dichromate method, *TSS* = total suspended solids.
Source: own study.

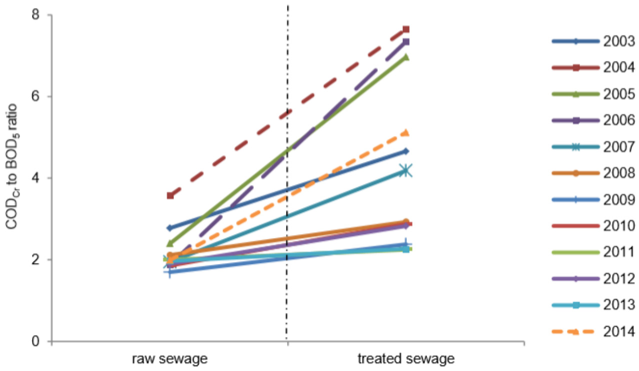


Fig. 3. A susceptibility of the raw sewage and treated sewage on biodegradability based on COD_{Cr}/BOD_5 ratio; BOD_5 and COD_{Cr} as in Table 1; source: own study

The result in Table 1, for raw sewage indicated that the range between the minimum and maximum BOD_5 value was 2100 mg $O_2 \cdot dm^{-3}$. In turn, the minimum and maximum COD_{Cr} value was 268 and 6117 mg $O_2 \cdot dm^{-3}$. For total suspended solids (*TSS*), a different between the minimum and maximum concentration in raw sewage was 2838 mg$\cdot dm^{-3}$. Presented results for BOD_5, COD_{Cr} and *TSS* in inflow wastewater to treatment plant in Siepraw, indicated that the range of pollutions concentration in raw sewage is much wider then this which is presented in literature sources [BŁAŻEJEWSKI 2003; HEIDRICH, WITKOWSKI 2005; KACZOR 2009]. Based on the result of coefficient of variation C_v (Tab. 1), it can be stand that pollutions indicators values were characterized by a considerable variation in raw sewage [MUCHA 1999]. The high variability of pollutant concentrations, could have been caused by illegal discharge of industrial wastewater from: butcheries, slaughterhouses or fruit and vegetable processing plants, which are characterized by very high pollution loads.

Table 1 also presented the statistical characteristic of the efficiency removal of organic and suspended solids compounds in outflow of wastewater. For the BOD_5, a different between the minimum and maximum value was 100.3 mg $O_2 \cdot dm^{-3}$. For the whole investigation period, 21% of the observation exceeded the limitation value, which according to Rozporządzenie… [2014] is equal 40 mg $O_2 \cdot dm^{-3}$. In turn, the statistical range of COD_{Cr} value was 199.5 mg $O_2 \cdot dm^{-3}$, and the of its permissible level of 150 mg $O_2 \cdot dm^{-3}$, was exceeded three times during the research period. Its mean that 8% of the observation exceeded the limitation value in investigation period. For total suspended solids (*TSS*), the range between the minimum and maximum concentration was equal 102.8 mg$\cdot dm^{-3}$. During the research period only 3 samples of treated sewage (8% of all) exceeded the permissible level of *TSS*, which is equal 40 mg$\cdot dm^{-3}$. The results above the permissible values of pollutions indicators in treated sewage may be case by many different factors. For these factors include: sewage inflow irregularity, pollution content irregularity, temperature in bioreactor, active sludge condition. Increased values of pollution indicators (BOD_5, COD_{Cr}, *TSS*) in research period could be result from increase of pollution concentration in inflow of wastewater, which was observed. Nowadays, especially rural inhabitants without access to sewage system are still use septic tanks as a way to drain sewage from homes. The high price of water and the costs, associated with periodic waste water disposal, caused that the inhabitants are accustomed to save the water. That can be the reason for the higher pollution concentration in smaller sewage volume [BARTON *et al.* 2015; MŁYŃSKI *et al.* 2019]. According to coefficient of variation (*Cv*), it was found that pollutants indicators values were characterized by a high variation. The similar research results were presented by MŁYŃSKI *et al.* [2019], WAŁĘGA *et al.* [2018] and BUGAJSKI *et al.* [2016], what indicates that this variability of the pollution concentration is typical for household sewage.

According to the results presented in Figure 3, it can be observed that the sewage inflow in research period (2003–2014) characterized the by average and poor biodegradability mostly. After mechanical and biological treatment process, was observed high organic pollution distribution and high concentration of hard-biodegradable compounds in outflow of wastewater. This is indicated by the increase in value between COD_{Cr} and BOD_5 ratio in treated sewage. Similar results in raw and treated sewage was presented by MŁYŃSKA *et al.* [2017], authors also observed the increase of COD_{Cr} and BOD_5 ratio in treated sewage. Calculated values of ratio between COD_{Cr} and BOD_5 mean, that the mechanical but mainly biological process of treated wastewater, occurred correctly in wastewater treatment plant in Siepraw.

The values of reliability/reduction coefficient in research period were determined in Table 2. Based on the obtained results, it can be stated that the wastewater treatment plant in Siepraw works properly. For the first of pollutions indicators from organic group (BOD_5) the average value of reduction indicator in whole period of research was equal 94%. Only in 2009 year, was observed that the value of reduction, decreased under 90% (was equal 87%). In the years: 2008, 2009 and 2011 the permissible BOD_5

Table 2. The values of reliability coefficient (*RF*) and reduction coefficient (η) of investigated parameters in research period from 2003 to 2014

Year	Pollution indicators					
	BOD_5		COD_{Cr}		*TSS*	
	(%)					
	η	*RF*	η	*RF*	η	*RF*
2003	98	35	94	38	95	39
2004	96	37	92	64	95	56
2005	98	39	96	61	96	62
2006	96	29	82	59	91	39
2007	93	43	85	43	96	49
2008	91	143	86	108	89	115
2009	87	141	83	86	89	61
2010	94	82	90	64	97	33
2011	93	143	91	85	90	123
2012	93	68	92	46	94	39
2013	94	62	92	37	96	30
2014	94	29	94	27	96	12
2003–2014	**94**	**71**	**89**	**60**	**94**	**54**

Explanations: BOD_5, COD_{Cr} and *TSS* as in Table 1.
Source: own study.

values were exceeded in treated wastewater. The value of reliability factor (*RF*) was properly equal in 2008 – 143%, in 2009 – 141% and in 2011 – 143%. The excess of BOD_5 concentration in outflow did not influent of high work effectiveness of wastewater treatment plant on Siepraw. The average value of reduction coefficient for COD_{Cr} in research period was equal 89%. Also for this pollution indicator in 2008, 2009 and 2011 noted the excess of the permission value (150 mg $O_2 \cdot dm^{-3}$). In these years the reliability factor value was higher, and properly equal: 108% in 2008, 86% in 2009 and 85% in 2011. Obtained results showed that the sewage treatment process provide an effectiveness *TSS* reduction. The average value of reduction coefficient (η) in research period was equal 96%. Whereas the value of *RF* parameters showed, that exceed of the permissible *TSS* concentration was observed in 2008 and 2011. According to this the value of this parameters in these years were properly equal: 115% and 123%. However, the numbers of samples with increased pollutant concentration, did not cause significant decrease effectiveness of the treatment process of wastewater treatment in Siepraw in 2003 to 2014.

The reliability of the considered of pollutions indicators was determined using the Weibull reliability method. A hypothesis that the Weibull distribution could be used to approximate the empirical data was verified for estimated parameters of distribution. The probability (*p*) values for BOD_5, COD_{Cr} and *TSS* showed, that the empirical data could be described by the Weibull distribute ($p > 0.05$). The goodness of fit the Weibull distribution to the estimated parameters was tested with the Hollander–Proschan test. The results of the analyses are presented in Table 3. Performed analysis showed, that the Weibull distribution describe, empirical data at the significance level for BOD_5, COD_{Cr} and *TSS* with a probability of 82.5%, 83.8% and 75.1%.

According to the result of Weibull distribution Figure 4 shows the BOD_5, COD_{Cr} and *TSS* value, and reliability of

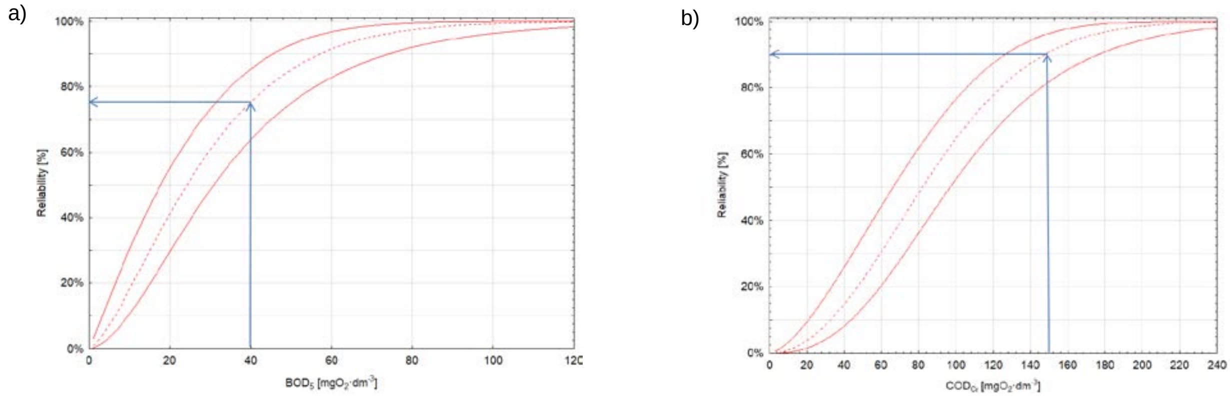
Table 3. Results of the estimation of the Weibull distribution parameters with the measure of goodness of fit to empirical data

Indicator	Distribution parameters			Hollander–Proschan test	
	scale (*b*)	shape (*c*)	location (θ)	test value	*p*
BOD_5	31.4202	1.3969	0.50108	0.221029	0.82507
COD_{Cr}	98.1280	2.0457	0.61235	0.204721	0.83779
TSS	27.3870	1.3117	0.502617	0.317535	0.75084

Explanations: test probability: if $p \leq 0.05$ it should be reject the null hypothesis that the empirical data can be described by Weibull distribution, BOD_5, COD_{Cr} and TSS as in Tab. 1.
Source: own study.

remove this pollution indicator. Vertical axis presents the reliability given in % on a scale from 0 to 100 and horizontal axis shows the pollutions indicators value given in $mg \cdot dm^{-3}$. The technological reliability for BOD_5 removal to the required limit concentration of 40 mg $O_2 \cdot dm^{-3}$ mg was equal 75% (Fig. 4a). Thus, the permissible concentration of this parameter in the effluent wastewater could be observed on almost 274 days. In turn, Figure 4b shows, the technological reliability of removal of COD_{Cr} to the maximum value of 150 mg $O_2 \cdot dm^{-3}$ was 90% in research period. That's mean that the permissible value of this pollution indicator in effluent sewage could be observed on almost 329 days. Figure 4c shows that the technological reliability for *TSS* removal to the required limit concentration equal 50 mg $O_2 \cdot dm^{-3}$ mg was 89.5%. According to the result of technological reliability, it means that the concentration of *TSS* in the effluent could exceed the discharge limit on 38 days a year.

In paper of ANDRAKA and DZENIS [2003] was presented the guidelines of treatment plant which characterized by a $PE \leq 2\,000$, that should operate a reliability of at least 97.3% and a producer's risk of $\alpha = 0.05$. That is mean that the wastewater treatment plant in Siepraw is allowed to be inoperable for a maximum of 9 days per year. According to these guidelines the sewage treatment plant in Siepraw worked with the lower efficiency, although the preliminary analysis of values in pollutants indicators in the outflow, reduction and reliability factor suggested a high efficiency of object work. Lower of technological reliability level than 97.3% for organic pollution (BOD_5 and COD_{Cr}) and *TSS* were presented by MARZEC [2017]. In paper author presented three domestic wastewater treatment plants based on different technology. For the wastewater treatment plant with active sludge, the value of reliability removal of BOD_5 equal 70%, COD_{Cr} was 87% and *TSS* equal 66%. Also in another study of small wastewater treatment plant by BUGAJSKI and WAŁĘGA [2010], showed a lower level of reliability. Technological reliability during the research period from 2000 to 2003 year, was characterized by the following BOD_5, COD_{Cr} and *TSS* removal reliability levels: 72%, 93% and 66%. The results from paper and these presented also by other authors of technological reliability confirmed the low work efficiency of small wastewater treatment plant with active sludge. According to the data lead to very general conclusion that this kind of object shouldn't be used in the agglomeration below 2000 *PE*.



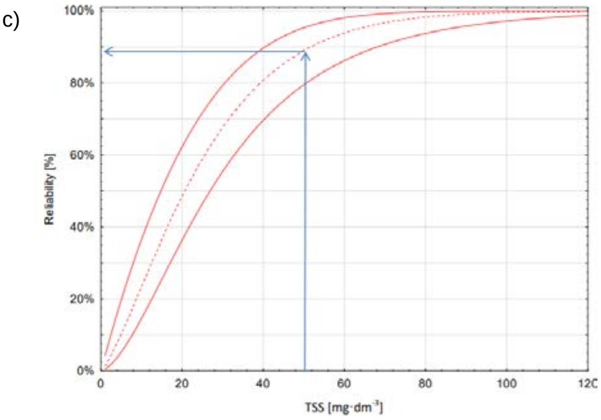


Fig. 4. Technological reliability in effluent for: a) BOD_5, b) COD_{Cr}, c) *TSS*; BOD_5, COD_{Cr} and *TSS* as in Tab. 1; source: own study

CONCLUSIONS

It was found that the average BOD_5, COD_{Cr} and *TSS* removal efficiencies over the research period (12 years) of the wastewater treatment plant in Siepraw amounted to 94%, 89% and 94%. In research period for all pollutants indicators observed the exceed of limit values in effluent wastewater, what was indicated by reliability factors values. The average reliability coefficient in treated sewage was in: BOD_5 equal 70%, COD_{Cr} was 60% and *TSS* equal 50%. The technological reliability, determined by means of the Weibull reliability method, was 75% in the case of BOD_5 removal, 90% in the case of COD_{Cr} removal and 89.5% in the case of *TSS*. According to the guideline presented in literature sources, work of wastewater treatment plant in Siepraw wasn't satisfied, because the technological reliability in period from 2003 to 2014, was lower than 97.3% for all research parameters.

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