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Optimizing Treatment of Cesspool Wastewater at an Activated Sludge Plant

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Abstract: The purpose of this work was to determine the optimal percentage of wastewater from cesspool in the mixture of wastes subjected to treatment processes, which will not have a negative impact on the functioning of the collective treatment plant. The study was carried out over a period of two years, with 48 samples of wastewater flowing in from the sewage network and delivered with the slurry tanker collected and subjected to physical and chemical analysis. The analysis included: Biochemical Oxygen Demand (BOD_5), Chemical Oxygen Demand (COD), and Total Nitrogen (TN). In addition, the study defined the daily balance of the amount of inflowing and transported wastewater. Based on the analysis carried out, it was found that the unit loads of BOD_5, COD and TN in the mixture of wastewater subjected to the treatment process will be at the level of loads assumed in the project, when the share of supplied wastewater, i.e., from cesspool, will be at the level of 5% of the total amount of wastewater. Considering that in the analysed period the total average daily amount of wastewater subjected to the treatment process was 253.5 $m^3 \cdot d^{-1}$, the optimal amount of wastewater delivered should be 12.7 m^3 in each day of the week.

Keywords: wastewater; sewerage; liquid waste tanks (cesspool); partial correlation; organic and biogenic pollution

1. Introduction

Along with the growing expansion of housing construction in rural areas in Poland, the volume of water used by residents increases, thus also the volume of generated sewage increases. Unfortunately, in many cases, professional water supply and sewage systems are not provided along with the expansion of housing. In Poland, in areas where there are no collective sewage systems, residents use the so-called septic tanks (tanks for liquid waste) in which sewage is collected for disposal to a collective treatment plant. The numbers show how big this problem is in Poland.

In rural areas, according to current Central Statistical Office (CSO) data [1], in 2018 there were 21,775.50 thousand tanks for liquid waste, commonly known as cesspool. It still is the most common way of wastewater disposal in Poland, in rural areas where there are no collective or individual sewage systems. The correct operation of such tanks consists in regular emptying of wastewater, which should then be transported by a professional slurry tanker to a collective wastewater treatment plant, whose technological line is suitable to treat this type of wastewater. Unfortunately, according to national literature reports, many such tanks are improperly used by residents, because the wastewater coming from them goes illegally to the environment, i.e., land or flowing water [2–4]. Such practices lead to pollution of land, surface and underground waters [5]. The main reason for this is the intention of users to reduce the costs of exporting and utilizing wastewater from cesspits in a collective treatment plant. To prevent this type of practice, it is necessary to control the leak-tightness of this type of tanks and the regularity of their emptying by a professional company with the appropriate slurry tanker.

Another problem posed by wastewater from cesspool is their utilization in a collective wastewater treatment plant, because the concentrations of pollutants contained in them are often several times, and sometimes several dozen times, higher than typical wastewater flowing into the sewage system [6–8]. High concentrations of pollutants in wastewater from cesspool result from the saving habits of residents to save and thus use a small amount of water, which results in an increase in the concentration of pollutants [9,10]. In addition, the long-term storage of wastewater in tanks creates the conditions for anaerobic decomposition of organic pollutants and the occurrence of sewage rotting, which causes the release of an unpleasant odour of hydrogen sulfide [11–13]. The volume of liquid waste tanks should be designed to be emptied with a 3–4 week time interval. Too long intervals between emptying these tanks result in the wastewater being rotten and similar in composition to sewage sludge with very high hydration [14]. In practice, wastewater from cesspools is transported to the area of the collective wastewater treatment plant on an irregular basis on each day of the week [8,15], and this type of practice is conducive to disruption of biological wastewater treatment processes, as these processes are sensitive to major changes in both the quantity and quality of treated wastewater. Therefore, the amount of wastewater from cesspool should be dosed (batched) with great caution to the total amount of wastewater subjected to treatment [16–20]. Adding (mixing) in a short time, e.g., directly from the slurry tanker sewage from cesspool to sewage flowing into the sewage network, will result in a sudden increase in the amount of treated sewage, as well as a sudden increase in the so-called "impact" of the pollutant load in the wastewater mixture subjected to the treatment process [21].

As it has been shown in the publications concerning the problem of neutralization of sewage from septic tanks, there are alternative treatment systems to transport to collective treatment plants, which is an expensive process and may have a negative impact on biological processes in collective treatment plants. As Forbis-Stokes et al. [21] stated, it is possible to treat sewage from septic tanks with a mobile installation at the place where they are generated. Another solution in this aspect is the treatment of sewage from septic tanks in wetland sewage treatment plants. As Jong and Tang [22] stated, wetland wastewater treatment plants, while maintaining an appropriate operating regime, demonstrate high efficiency in septic tank waste material treatment. In addition, as Mancl and Rosencrans indicated, it is possible to drain sewage from septic tanks into properly prepared fields, which allows water to be retained in the soil, thus increasing water retention, which is crucial nowadays [23].

However, in Poland, now and in the following years, the basis for the disposal of sewage from septic tanks is their selection and transport to a collective treatment plant. This applies to the majority of collective treatment plants in rural communes in Poland. Therefore, there is an urgent need to indicate the optimal proportion (volume) of sewage delivered by the slurry rolling stock, so that other sewage does not adversely affect the treatment of all sewage.

The overall aim of the analysis was to calculation an optimal organic and biogenic load into the wastewater treatment plant (WWTP) by blending strong cesspool wastewater with weak sanitary wastewater.

The detailed aim of the study was to determine the optimal percentage (amount) of sewage from cesspool in the mixture of wastes subjected to treatment processes, at which the unit load (Ul) of organic and biogenic pollutants will be at the level of the unit load assumed in the project for the wastewater treatment plant. The unit load of the analysed indicators assumed in the project is: 60 $g \cdot I^{-1} \cdot d^{-1}$ for Biochemical Oxygen Demand (BOD_5), 120 $g \cdot I^{-1} \cdot d^{-1}$ for Chemical Oxygen Demand (COD) and 13 $g \cdot I^{-1} \cdot d^{-1}$ for Total Nitrogen (TN). The study results have an important practical aspect, as many small, collective wastewater treatment plants in rural areas in Poland have problems with setting the daily limit of sewage delivered by the slurry tanker, which will not adversely affect the functioning of the facility. The novelty of this work is the answer to an important question asked by the operators of wastewater treatment plants in Poland: "How much sewage from cesspool that is transported by slurry tanker can be introduced into the technological system of the wastewater treatment plant, so as not to disturb the purification processes?" The test results presented in this publication indicate the need to build or modernize technological systems for the collection and uniform dosing of collective wastewater from cesspools, so that this wastewater does not adversely affect biological treatment processes in wastewater treatment plants with bioreactors with activated sludge.

2. Materials and Methods

2.1. Characteristics of the Sewerage System

The analysed sewage system includes a sewage network with a total length of 6900 m and a diameter of collectors DN = 0.2 m together with a collective sewage treatment plant, whose designed daily average capacity is 500 $m^3 \cdot d^{-1}$. During the study period, 360 residential buildings were connected to the sewer network. The technological system of the sewage treatment plant consists of a dense grate, a sand pit with a grease and oil separator and a radial bioreactor with a central integrated secondary settling tank. The diameter of the bioreactor is DN = 11 m, with a depth of H = 5.9 m, while the diameter of the secondary settling tank is DN = 3.5 m, with a depth of H = 5.9 m. After mechanical treatment, the sewage flows to the bioreactor, where its biological treatment takes place. The wastewater flows into the nitrification zone and then into the denitrification zone. The sewage then flows to the secondary settling tank from where, after the sedimentation of the deposits, it flows to the river (stream without proper name). The wastewater treatment plant station also has a sewage catchment station transported by a slurry tanker from cesspool. In the commune, where there is no sewage system, most residential buildings have tanks for liquid impurities, cesspool from which wastewater is transported by means of slurry tanker to the treatment plant on weekdays. The scheme of the technological layout of the wastewater treatment plant is presented in Figure 1.

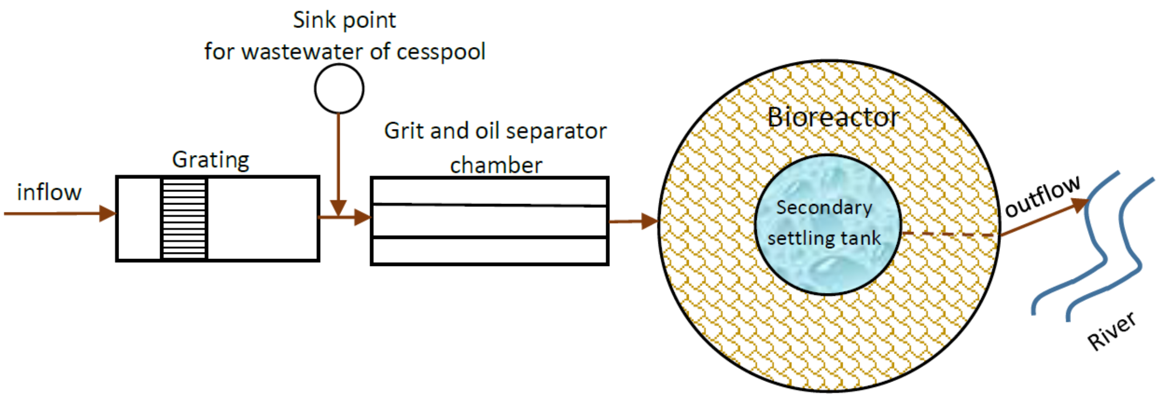

Figure 1. Scheme of the technological layout of the wastewater treatment plant (WWTP).

2.2. Analytical Methods

The study was carried out in the period of two years, 2013 and 2014. During this period, 48 samples of wastewater flowing in from the sewage network and delivered with the slurry tanker were collected and analysed. Incoming wastewater samples were taken from the inflow channel using an autosampler type wastewater sampling device that was programmed for the wastewater flow rate. On the other hand, samples of wastewater from cesspool were taken from the drainage station ("Sink point" on Figure 1). Impurity indicators, BOD_5, COD, and TN, were analysed in both types of wastewater. Samples of wastewater were subjected to the physical–chemical analysis in accordance with reference methods set out in the applicable legal acts.

- BOD_5—measurement of oxygen after 5 days of incubation at 20 °C in OXI TOP—197 WTW
- COD_{cr}—the bichromate method according to PN-ISO 6060: 2006
- Total Nitrogen (Kjeldahl) according to PN-EN 25663: 200

In the days on which the wastewater samples were taken, the amount of wastewater of inflowing Q_1 and the amount supplied of wastewater from cesspools Q_2 were also determined. The amount of flowing wastewater was measured using measuring systems consisting of a probe of the level of the wastewater mirror above the triangular overflow located in the drainage channel. The amount of sewage delivered was determined on the basis of entries in the operating log regarding the amount of sewage delivered with the slurry tanker.

3. Results and Discussion

During the tests, the average daily sewage inflow from the sewage network amounted to Q_1 = 238.5 $m^3 \cdot d^{-1}$ to the said sewage treatment plant, while the average daily sewage delivered by the slurry tanker was Q_2 = 15.1 $m^3 \cdot d^{-1}$, which constituted 5.7% of their share in the total amount of wastewater subjected to the treatment process. However, the amount and frequency of wastewater from cesspool and transported by slurry tanker to the treatment plant was irregular on each day of the week. Wastewater from cesspools was delivered only on weekdays, i.e., from Monday to Friday. In the examined period, on weekdays, the amount of sewage delivered ranged from 5 to 28 $m^3 \cdot d^{-1}$. This represented from 2.1% to 12.4% (median 13.5 $m^3 \cdot d^{-1}$) of their share in the total amount of treated wastewater. This type of irregular delivery of wastewater from cesspools to the treatment plant is undesirable, as the irregularity of the amount of sewage flowing in and the load of pollutants contained in it causes disruption of wastewater treatment processes [7,16–18].

In the introductory part of the analysis on the quality of treated wastewater, the study presents pollutant indicators in wastewater flowing in from the sewage network and in wastewater from cesspool supplied by slurry tanker. In inflowing wastewater, the BOD_5 median value was 236.0 $mg \cdot dm^{-3}$, the COD median value was 390.0 mg·dm-3, while the median of TN concentration was 57.5 $mg \cdot dm^{-3}$. In inflowing sewage, the coefficient of variation for BOD_5 was Cv = 18%, for COD it was Cv = 14%, and for Total Nitrogen it was Cv = 13%, which indicates in all cases a small differentiation of this indicator according to the scale proposed by Mucha [24]. Based on the results of analyses regarding the size of pollutant indicators in inflowing wastewater, it was found that their values corresponded to typical domestic sewage described in the literature [25–28]. The median value of the analysed indicators in sewage from cesspool was as follows: for BOD_5—3825.0 $mg \cdot dm^{-3}$, for COD—7750.0 $mg \cdot dm^{-3}$, and for TN—585.0 $mg \cdot dm^{-3}$. As demonstrated, the values of indicators in wastewater from non-drainage tanks are much higher than the inflowing wastewater, which is confirmed by literature reports on the quality of wastewater from cesspool [6,8]. The variability of the values of the analysed indicators in wastewater was delivered at the level of mean variability according to the Mucha scale [24]. The coefficient of variation Cv oscillated between 20% and 25%. Characteristic values of the analysed indicators in inflowing and delivered wastewater are presented in Table 1.

Table 1. Statistical characteristics of concentration indicators of contamination in raw wastewater from sewer system and from cesspool.

Parameters	Types of Wastewater	Statistics					
		Average $mg \cdot dm^{-3}$	Median $mg \cdot dm^{-3}$	Min. $mg \cdot dm^{-3}$	Max. $mg \cdot dm^{-3}$	Standard Deviation $mg \cdot dm^{-3}$	Coefficient of Variation %
Biochemical Oxygen Demand (BOD_5)	sewers	242.8	236.0	178.0	340.0	42.7	18
	cesspool	4005.6	3825.0	1560.0	6530.0	1003.9	25
Chemical Oxygen Demand (COD)	sewers	387.1	390.0	253.0	493.0	52.4	14
	cesspool	7595.3	7750.0	4390.0	9870.0	1489.5	20
Total Nitrogen (TN)	sewers	57.2	57.5	39.0	73.0	7.2	13
	cesspool	592.7	585.0	380.0	810.0	124.9	21

To determine the optimal, i.e., design unit load of the analysed indicators, i.e., BOD_5, COD and TN in the wastewater mixture subjected to the treatment process, an analysis was carried out in the following stages:

- Determination of the concentration of indicators in the mixture of inflowing sewage;
- Determination of the unit load of indicators in inflowing sewage;
- Determination of the unit load of indicators in the mixture of inflowing and delivered wastewater;
- Determining the optimal share of the amount of wastewater delivered in the total wastewater mixture so as to obtain the concentrations assumed in the project.

Based on the values of the analysed indicators, i.e., BOD_5, COD and TN in inflowing sewage and delivered sewage from cesspools as well as taking into account the quantitative balance of both types of sewage, the value of these indicators was calculated in the mixture of sewage subjected to the treatment process. In order to calculate the values of the analysed indicators in the wastewater mixture, the weighted average formula was used (1):

$$W_a = \frac{W_1 \cdot Q_1 + W_2 \cdot Q_2}{Q_1 + Q_2} \tag{1}$$

where:

W_a—value of the indicator in the wastewater mixture ($g \cdot m^{-3}$);
W_1—value of the indicator in inflowing wastewater ($g \cdot m^{-3}$);
W_2—value of the indicator in delivered wastewater ($g \cdot m^{-3}$);
Q_1—amount of inflowing sewage ($m^3 \cdot d^{-1}$);
Q_2—amount of sewage delivered ($m^3 \cdot d^{-1}$).

Based on the results of the calculated weighted average (1), it was found that the median BOD_5 value in the wastewater mixture was 438.5 $mg \cdot dm^{-3}$, the median COD was 773.1 $mg \cdot dm^{-3}$ and the median TN was 89.3 $mg \cdot dm^{-3}$. With regard to organic indicators in the wastewater mixture, the range of values for BOD_5 ranged from 247.0 to 815.6 $mg \cdot dm^{-3}$, while for COD it was from 415.6 to 1495.8 $mg \cdot dm^{-3}$. In both cases, the variability of the values of these indicators expressed by the coefficient of variation Cv was 28%, which indicates their average differentiation. The range of TN concentration in the wastewater mixture oscillated from 57.4 to 126.0 $mg \cdot dm^{-3}$ and was characterized by a small variation at the level of Cv = 18%.

The next stage of the analysis was to determine in the wastewater flowing from the sewage network a unit load of organic pollutants expressed as BOD_5 and COD and a unit load of biogenic pollutants expressed as TN. In order to calculate the unit load (per one inhabitant) of individual pollution indicators, Formula (2) was used:

$$UL_i = \frac{W_x \cdot Q_1}{In} \tag{2}$$

where:

UL_i—unit load of the indicator in inflowing wastewater ($g \cdot I^{-1} \cdot d^{-1}$);
W_x—concentration of indicator in inflowing wastewater ($g \cdot m^{-3}$);
Q_1—amount of inflowing wastewater ($m^3 \cdot d^{-1}$);
In—total number of inhabitants connected to the sewage network (In = 1200).

In wastewater flowing from the sewage network, the median BOD_5 unit load was 46.1 $g \cdot I^{-1} \cdot d^{-1}$ and it was a 23.2% lower BOD_5 unit load than assumed in the project. The median COD load was 75.7 $g \cdot I^{-1} \cdot d^{-1}$ and was lower by 36.9% for the load assumed in the project. In the case of unit load of TN in inflowing wastewater, it was found that the median of this parameter was 11.4 $g \cdot I^{-1} \cdot d^{-1}$ and it was smaller than assumed by 18.6%. As can be seen in all 3 cases, the unit load of the analysed indicators was lower as a result of design assumptions. Characteristic unit loads of the analysed indicators in the inflow wastewater are presented in Table 2. Based on the calculated coefficients of variation Cv for the unit loads of the analysed indicators in the inflow wastewater, it was found that they were at the level of average differentiation during the test period.

Table 2. Statistical characteristics of unit load of analysed indicators in inflow wastewater.

Parameters	**Statistics**					
	Average $g \cdot I^{-1} \cdot d^{-1}$	**Median** $g \cdot I^{-1} \cdot d^{-1}$	**Min.** $g \cdot I^{-1} \cdot d^{-1}$	**Max.** $g \cdot I^{-1} \cdot d^{-1}$	**Standard Deviation** $g \cdot I^{-1} \cdot d^{-1}$	**Coefficient of Variation %**
BOD_5	48.3	46.1	29.4	81.3	11.5	24
COD	77.1	75.7	41.7	123.7	15.9	21
TN	11.4	11.4	6.9	17.5	2.3	20

The reason for the unit load lower than assumed in the design of the organic and biogenic indicators tested is the inflow of accidental (rainfall) and infiltration waters to the sewage system. According to the interview with the operator of the sewage system in question, rainwater is discharged into the sewage network from illegally connected roof gutters from residential buildings. As Kaczor et al. [29] and Nowobilska-Majewska and Bugajski [30] indicated, the inflow of rainwater to the sewage network significantly reduces the concentration of organic and biogenic pollutants in the wastewater subject to treatment. Rainwater entering the sewage system intended for the disposal of only domestic sewage affects periodic disruptions in the operation of sewage treatment plants and causes higher costs of wastewater treatment [29,31]. In addition, the analysed sewage network is partly located under the groundwater occurrence level, which causes groundwater to flow into the sewer collectors through leaks in their connections. The foundation of sewer collectors below the groundwater level causes that these waters infiltrate the collectors through all kinds of leaks and causes an increase in the amount of wastewater flowing into the treatment plant [32]. As Madryas et al. described in their research [33], the intensity of the infiltration water inflow to sewage channels is directly proportional to the height of the groundwater table above the pipe.

Because the treatment process is subjected to a mixture of inflowing and delivered wastewater from cesspool, the size of unit loads for BOD_5, COD and TN in the wastewater mixture is analysed using Formula (3). To calculate the unit load in the wastewater mixture, the sum of Q_1 inflows and Q_2 supplied wastewater was adopted, and its weighted average was used as the value of the given indicator.

$$\text{ULmix.} = \frac{W_a \cdot (Q_1 + Q_2)}{\text{In} + \text{Ic}} \quad (3)$$

where:

ULmix.—unit indicator load in the wastewater mixture ($g \cdot I^{-1} \cdot d^{-1}$);
W_a—weighted average indicator in the wastewater mixture ($g \cdot m^{-3}$);
Q_1—amount of inflowing wastewater ($m^3 \cdot d^{-1}$);
Q_2—amount of wastewater delivered ($m^3 \cdot d^{-1}$);
In—total number of inhabitants connected to the sewage network (In = 1200);
Ic—number of inhabitants served by the slurry tanker-average per day (Ic = 10).

In the mixture of inflowing and delivered wastewater, which were subjected to the treatment process, the median unit load of BOD_5 was 90.5 $g \cdot I^{-1} \cdot d^{-1}$, and it was higher than the designed value (60 $g \cdot I^{-1} \cdot d^{-1}$) by 50.8%. The median COD in mixed wastewater was 155.2 $g \cdot I^{-1} \cdot d^{-1}$. Compared to the designed (120 $g \cdot I^{-1} \cdot d^{-1}$) unit load of COD, it was higher by 29.3%. The median TN in mixed wastewater was 18.5 $g \cdot I^{-1} \cdot d^{-1}$ and it was higher than the value assumed in the design (13 $g \cdot I^{-1} \cdot d^{-1}$) by 42.3%. As stated in all 3 cases, the unit load volumes of the analysed indicators in the wastewater mixture were significantly higher than the load assumed in the project. At the same time, it should be noted that this type of situation only took place on days when wastewater was delivered by means of slurry tanker. In relation to the unit load of the analysed indicators in the wastewater mixture, a greater unevenness was observed compared to the unit load of these indicators in the inflowing sewage. The unevenness of the unit load in the wastewater mixture expressed as the coefficient of unevenness Cv was for BOD_5—35%, for COD—35% and for TN—26%. Characteristics of unit load of analysed indicators in mixed wastewater are presented in Table 3.

Table 3. Statistical characteristics of unit load of analysed indicators in mixed wastewater.

Parameters	Statistics					
	Average $g \cdot I^{-1} \cdot d^{-1}$	Median $g \cdot I^{-1} \cdot d^{-1}$	Min. $g \cdot I^{-1} \cdot d^{-1}$	Max. $g \cdot I^{-1} \cdot d^{-1}$	Standard Deviation $g \cdot I^{-1} \cdot d^{-1}$	Coefficient of Variation %
BOD_5	99.5	90.5	39.8	185.7	35.1	35
COD	172.6	155.2	67.0	297.7	59.7	35
TN	18.7	18.5	10.3	30.5	4.8	26

Based on the analysis of the unit load of individual indicators in the inflow sewage and in the mixture of inflowing and delivered sewage, it was found that the unit load of the indicators in the inflowing sewage is lower than assumed in the project, while the unit load in the sewage mixture is too high in relation to the specified load in the sewage treatment plant design.

Because it was found that in the wastewater mixture, the unit load of the examined indicators increases with the increasing amount (percentage share) of added wastewater delivered by means of Pearson's linear correlation analysis, the following was determined:

- impact of the percentage (%) of wastewater delivered in the wastewater mixture on the unit load of the examined indicators;
- impact of the concentration of the analysed indicators in the delivered sewage on the unit load of these indicators in the sewage mixture.

Using the data covering the percentage (%) of the amount of wastewater delivered in the total wastewater mixture (independent variable) and the unit load data of the examined indicators in the wastewater mixture (dependent variable), the strength of the relationship of these two variables was determined in Figures 2–4.

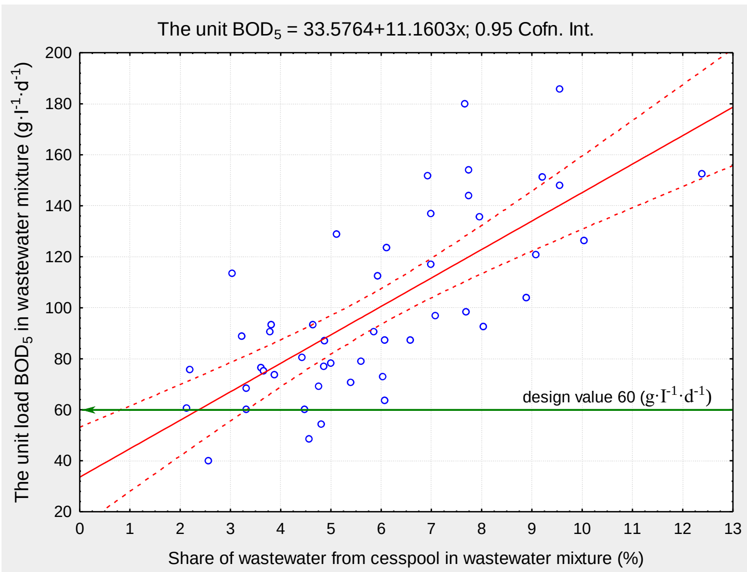

Figure 2. Connection share of wastewater from cesspool in wastewater mix (%) with unit load BOD_5 in wastewater mix and results of linear regression analysis.

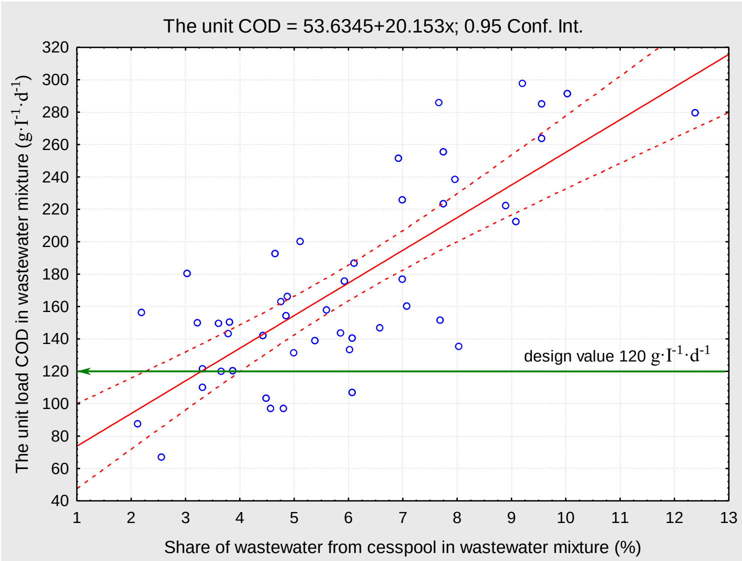

Figure 3. Connection share of wastewater from cesspool in wastewater mix (%) with unit load COD in wastewater mix and results of linear regression analysis.

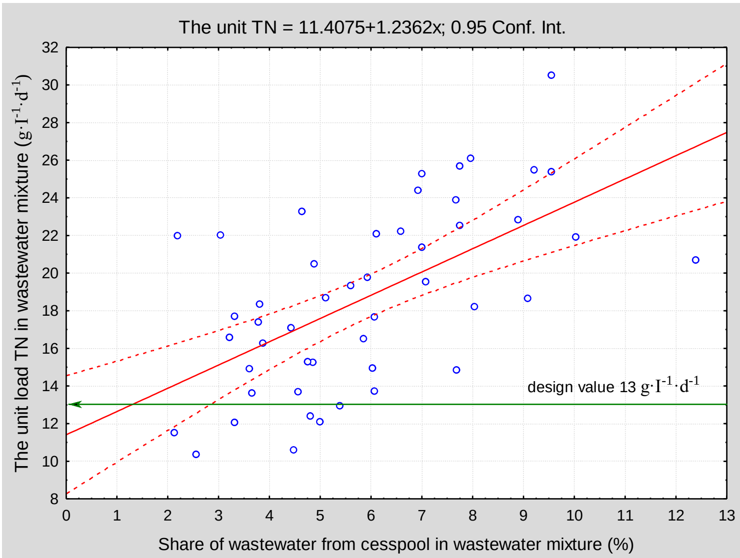

Figure 4. Connection share of wastewater from cesspool in wastewater mix (%) with unit load TN in wastewater mix and results of linear regression analysis.

Based on the analysis of the impact of the percentage of sewage delivered to the BOD_5 unit load in the sewage mixture, a correlation of r_{xy} = 0.73 was found, which in the scale proposed by Stanisz [34] defines this level of correlation as very high. In the analysed case, the correlation is statistically significant at the level of $\alpha = 0.05$. From the equation describing the regression line presented in Figure 2, it may be stated that a change (%) in the sewage supplied in the total sewage mixture by 1% causes a change in the BOD_5 unit load by 11.1 $g{\cdot}I^{-1}{\cdot}d^{-1}$. The dependence of the influence of the percentage of sewage delivered to the COD unit load in the sewage mixture was determined at the level of r_{xy} = 0.78, which also indicates the relationship of these variables at a very high level. In the case of the COD load from the equation describing the regression line shown in Figure 3, it is stated that a change in the proportion (%) of sewage delivered in the total sewage mixture by 1% causes a change in the COD unit load by 20.1 $g{\cdot}I^{-1}{\cdot}d^{-1}$. In the case of the analysed biogenic indicator, i.e., TN, the impact of the share (%) of sewage delivered on the unit load of Total Nitrogen in the wastewater mixture was at a high level, as indicated by the calculated correlation coefficient of r_{xy} = 0.59. From the equation describing the regression line presented in Figure 4, it can be stated that a change in the share (%) of sewage delivered in the total sewage mixture by 1% causes a change in the unit load of TN by 1.2 g·I^{-1}·d^{-1}. In all analysed cases of studied relationships, the correlation is statistically significant at the level of $\alpha = 0.05$.

In relation to the analysis of the correlation relationship between the concentration of organic and biogenic impurities (BOD_5, COD and TN) in the supplied wastewater and the size of the unit load of these parameters in the wastewater mixture, it was found that the correlation between the BOD_5 size of the delivered wastewater and the unit load of this parameter in the wastewater mixture is $r_{xy} = 0.61$. As follows from the equation describing the regression line in Figure 5, a change in BOD_5 value in the supplied sewage by 100 g·m^{-3} causes a change in the BOD_5 unit load in the sewage mixture by 2.1 g·I^{-1}·d^{-1}. The correlation of the COD value in the supplied sewage and the COD unit load in the sewage mixture was $r_{xy} = 0.52$. The equation describing the regression line in Figure 6 indicates that with a change in COD value of 100 g·m^{-3} in delivered sewage, there is a change in the COD unit load in the sewage mixture by 2.1 g·I^{-1}·d^{-1}. Whereas the correlation of the Total Nitrogen concentration in the supplied sewage and the unit load of Total Nitrogen in mixed sewage was $r_{xy} = 0.50$, and as the equation describing the regression line in Figure 7 shows, along with the change in the Total Nitrogen concentration in the sewage delivered by 100 g·m^{-3}, the unit load changes TN in sewage mixed by 1.8 g·I^{-1}·d^{-1}. The level of correlation of the analysed variables in all cases in the scale proposed by Stanisz [34] was high. In the analysed cases, the correlation is statistically significant at the level of $\alpha = 0.05$.

Because the variability of the unit load BOD_5, COD and Total Nitrogen in the wastewater mixture depends on the percentage (%) in them of wastewater from cesspits delivered to the sewage treatment plant by the slurry tanker and on the size of these parameters in the supplied sewage, a partial correlation analysis was performed. Partial correlation analysis will allow to determine simultaneously the strength (relationship) of the relationship of two dependent variables to one independent variable.

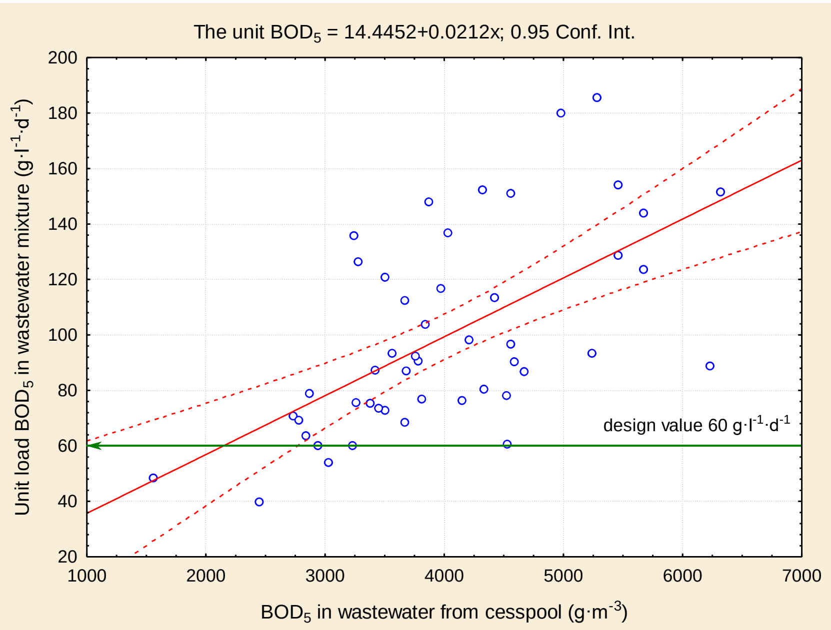

Figure 5. Connection BOD_5 in wastewater from cesspool with unit load BOD_5 in wastewater mix and results of linear regression analysis.

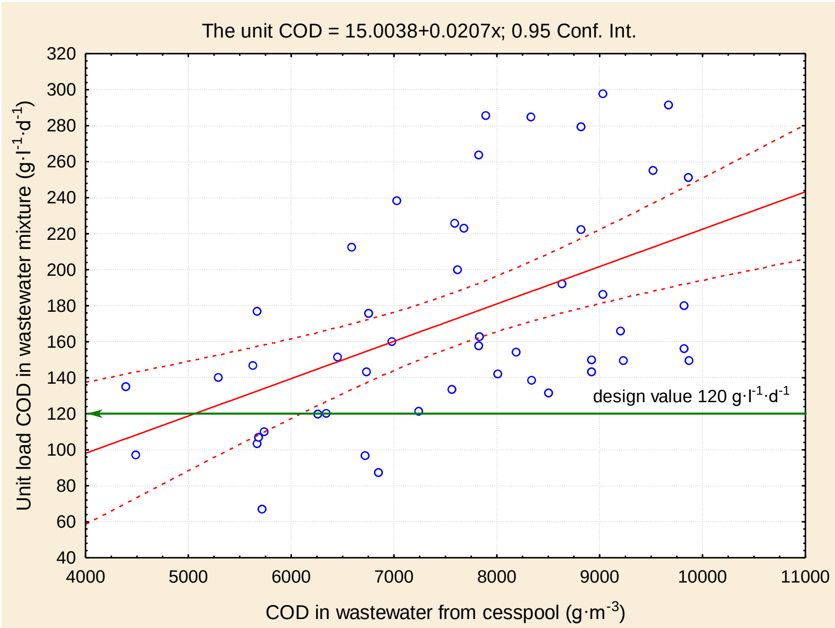

Figure 6. Connection COD in wastewater from cesspool with unit load COD in wastewater mix and results of linear regression analysis.

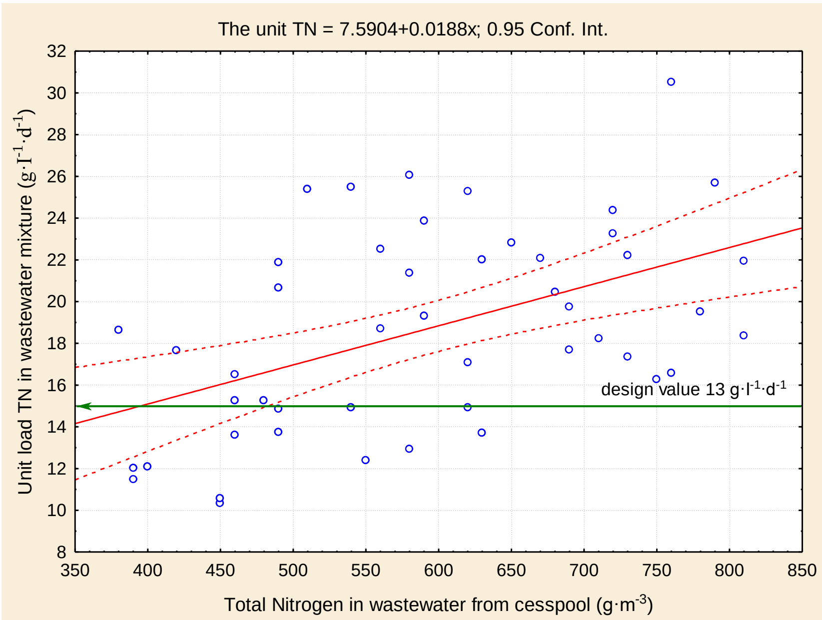

Figure 7. Connection TN in wastewater from cesspool with unit load TN in wastewater mix and results of linear regression analysis.

Based on the partial correlation analysis regarding the BOD_5 unit load in the wastewater mixture, it was found that the unit load of this parameter in the wastewater mixture depends on the percentage (%) of sewage delivered to them, as well as the value of this parameter in the supplied wastewater. However, the results of the partial correlation analysis indicate that the unit BOD_5 load in the wastewater mixture is more dependent on the percentage share of wastewater delivered than on the value of this indicator contained in it. The impact of the percentage of delivered wastewater on the BOD_5 unit load in the wastewater mixture was determined at the correlation level $R_c = 0.80$, while the impact of the BOD_5 value in the wastewater on the BOD_5 unit load in the total wastewater mixture was determined at the level of $R_c = 0.72$. On the scale provided by Stanisz [34], in both cases the relationship is at a very high level. The significance of the calculated correlation coefficients was tested by the Student's *t*-test at the significance level of $\alpha = 0.05$. In both cases, the significance of the studied relationships was found. In the case of partial correlation analysis regarding COD, it was found that the share of supplied sewage has a greater impact on the COD unit load in the wastewater mixture than the value of this parameter contained therein. The impact of the percentage share of sewage delivered to the COD unit load in the wastewater mixture was determined at the correlation level of $R_c = 0.87$, while the effect of the value of COD in the wastewater on the COD unit load in the total wastewater mixture was determined at the level of $R_c = 0.75$. In both cases, the correlation relationship is at a very high level, and the examined relationships are statistically significant at the level of $\alpha = 0.05$. With reference to the unit load of Total Nitrogen in the wastewater mixture, it was found that its concentration in the wastewater mixture at a very high level has a percentage (%) of the supplied wastewater, where $R_c = 0.72$, while at a high level, the effect of the concentration of this parameter in the wastewater was noted as delivered, where $R_c = 0.66$.

In order to indicate the optimal amount of supplied sewage, which was added to the inflowing sewage, so that the unit load of the analysed indicators was at the assumed level in the project, the nomograms are presented in Figures 8–10. Nomograms for individual indicators were developed based on the results of partial correlations. From the developed nomograms in Figures 8–10, it is possible to forecast (predict) the unit load of a given indicator in the wastewater mixture depending on the percentage (%) of wastewater delivered in the wastewater mixture and on the value ($g{\cdot}m^{-3}$) of this indicator in the supplied wastewater and the share percentage (%) of sewage delivered. The optimal load of the analysed indicators can be described by the formulas below:

- $ULmix_{BOD5}$ ($g{\cdot}I^{-1}{\cdot}d^{-1}$) = −28.7907 + 9.8888·$BOD_5$ in wastewater form cesspool + 0.0174% share of delivered wastewater
- $ULmix_{COD}$ ($g{\cdot}I^{-1}{\cdot}d^{-1}$) = −86.1077 + 19.4221·COD in wastewater form cesspool + 0.0190% share of delivered wastewater
- $ULmix_{TN}$ ($g{\cdot}I^{-1}{\cdot}d^{-1}$) = −1.2271 + 1.3171·TN in wastewater form cesspool + 0.0205% share of delivered wastewater

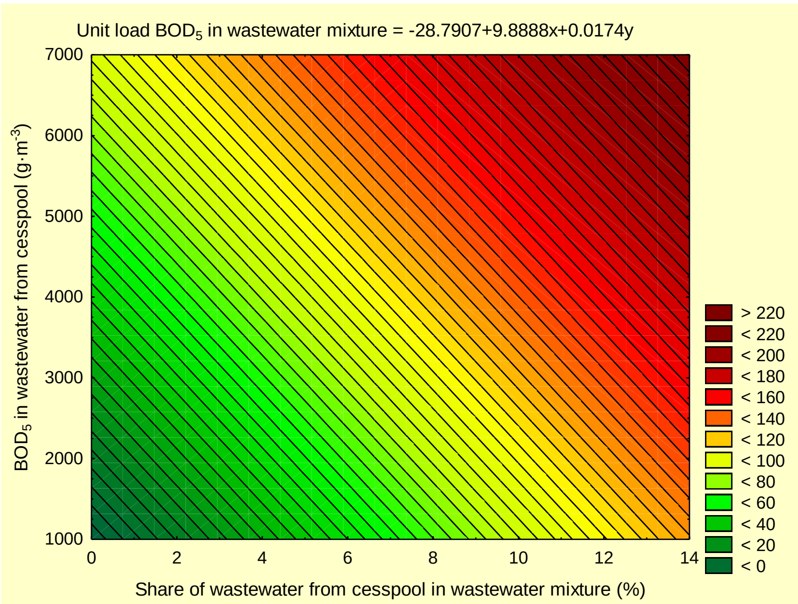

Figure 8. Nomogram to forecast unit load BOD_5 in the wastewater mix on the basis of percentage share of the inflow wastewater in the wastewater mix and the value BOD_5 in inflowing wastewater.

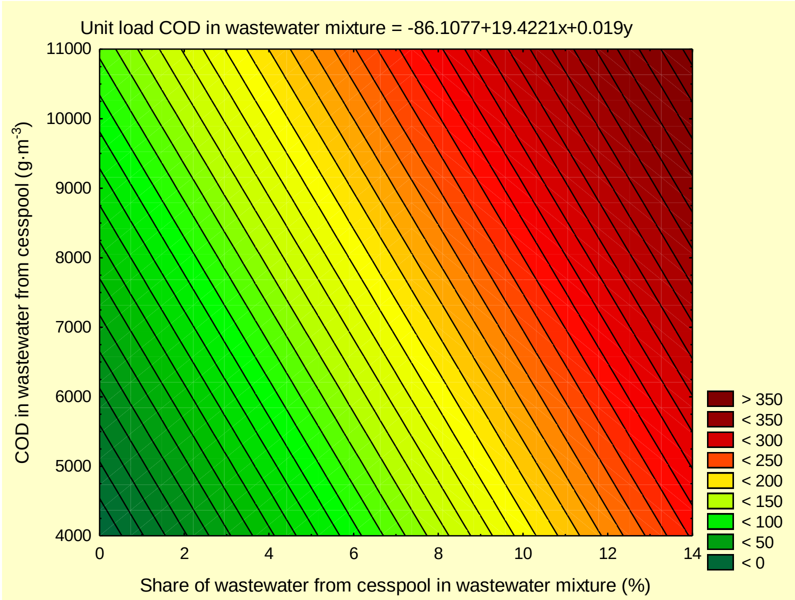

Figure 9. Nomogram to forecast unit load COD in the wastewater mix on the basis of percentage share of the inflow wastewater in the wastewater mix and the value COD in inflowing wastewater.

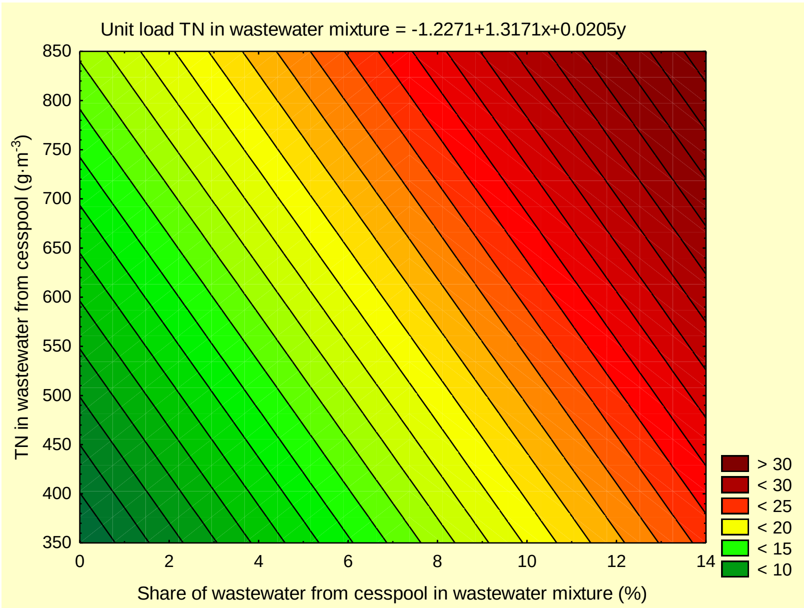

Figure 10. Nomogram to forecast unit load TN in the wastewater mix on the basis of percentage share of the inflow wastewater in the wastewater mix and the value TN in inflowing wastewater.

That the unit load in the wastewater subjected to the treatment process oscillated within the limits of the designed load, assuming that in delivered wastewater the median BOD_5 value is 3825.0 g·m^{-3}, the COD value is 7750.0 g·m^{-3} and the Total Nitrogen concentration is 585.0 g·m^{-3}, and the percentage of wastewater transported in the mixture should be between 4% and 6% (average 5%). Assuming the average daily amount of treated wastewater, which during the study period was 253.5 m^3·d^{-1}, the amount of wastewater transported by the slurry tanker should be from 10.2 m^3·d^{-1} to 15.2 m^3·d^{-1} (average 12.7 m^3·d^{-1}).

4. Conclusions

Based on the analysis carried out, it was found that the unit loads of BOD_5, COD and TN in the mixture of wastewater subjected to the treatment process will be at the level of loads assumed in the project, when the share of sewage delivered from cesspool will be at the level of 5% in the total amount of wastewater. Bearing in mind that the period of conducted research, where the total average daily amount of sewage was 253.5 $m^3 \cdot d^{-1}$, the amount of wastewater from cesspool delivered should be 12.7 $m^3 \cdot d^{-1}$. An important aspect and practical guideline for wastewater plants operators is the need for sewage-transported wastewater from cesspool to be dosing evenly every day of the week, including Saturday and Sunday, to the sewage flowing in from the sewage system. Because sewage from cesspool is delivered and mixed with sewage flowing only on weekdays, i.e., from Monday to Friday, it is advisable to build a tank with the right volume to collect sewage delivered so that it is possible to collect these wastes and then their even-dosing in an appropriate proportion on every day of the week. In the analysed case, the volume of the retention reservoir for the supplied sewage should provide a two-day volume resulting from the guidelines indicated in the analysis, i.e., 25.4 m^3 (2×12.7 $m^3 \cdot d^{-1}$). Moreover, it is very important that the wastewater from this reservoir is dosed evenly to the treatment system over the weekend, e.g., with an interval of 0.5 $m^3 \cdot h^{-1}$. The technological system of the wastewater treatment plant for the reception and dosage of sewage from septic tanks should be rebuilt. All supplied sewage should go to the collection point, then flow to the retention tank and then to the treatment technological system. The retention tank should be equipped with a properly programmed system (pump + controller) for even dosing of sewage to the process line of the treatment plant. Personnel servicing the sewage treatment plant should constantly monitor the amount of inflowing wastewater and its quality (concentration of pollution indicators) in order to determine the possibility of increasing the amount of sewage from cesspool, which may be an admixture of sewage subjected to the treatment process. Along with the extension of the sewage network in the commune, which will contribute to an increase in the amount of sewage flowing into the treatment plant, it is possible to increase the number of farms from which sewage from cesspool will be transported to the WWTP.

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