

Original Research

Optimizing the Percentage of Sewage from Septic Tanks for Stable Operation of a Wastewater Treatment Plant

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Abstract

Our paper shows how the quantity and quality of sewage from septic tanks affect the quantity and quality of mixed sewage undergoing a treatment process. The study was conducted in an exemplary small sewage system located in a rural commune. It lasted 24 months in 2013-14 and included an analysis of 24 samples of sewage collected both from septic tanks and the sewage system. The aim of the study was to determine an optimum amount of sewage supplied to the wastewater treatment plant (WTP) by vacuum trucks that would not cause significant fluctuations in the amount of organic waste expressed as BOD₅ and COD in the mixed sewage undergoing the treatment process. Partial correlation analysis showed that the quality of mixed sewage is to a greater extent affected by the percentage of sewage from septic tanks than by their pollution degree. The analysis of the effects of two independent variables (i.e., percentage share and pollution degree of the sewage from septic tanks) on a dependent variable (i.e., organic pollution of the mixed sewage allowed for a preparation of nomograms useful for forecasting the quality of sewage undergoing treatment). A simulation carried out for the investigated wastewater treatment plant, whose average daily treatment capacity was about 230 m³, showed that the amount of septic tank sewage should be around 11.5 m³·d⁻¹, that is 5% of the WTP capacity.

Keywords: sewage, sewage system, septic tanks, partial correlation, organic pollutants

Introduction

The guidelines set out in the National Program for Municipal Wastewater Treatment adopted as of 2003 stipulated that by the end of 2015 all municipal waste in Poland will be purified in a proper and professional manner [1-2]. In large urban areas these stipulations have been

fulfilled by the construction or modernization of regional wastewater treatment plants (WTP) in the last couple of years. However, they have not been met in rural areas where, according to Central Statistical Office of Poland (GUS), only 37.4% of inhabitants have the opportunity to discharge and dispose of domestic sewage [3]. Some buildings in these areas are connected to collective systems and a collective sewage-treatment plant, and some are equipped with onsite wastewater treatment systems [4, 5]. However, a large proportion of people living in non-urban

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areas who do not have the possibility of connecting to a sewage system and do not use onsite wastewater treatment systems collect their domestic waste in septic tanks. These septic tanks are emptied by vacuum trucks and the sewage is transported to a collective wastewater treatment plant [6]. The use of septic tanks requires their proper maintenance [7-9]. They should be properly dimensioned, that is to have such a capacity that requires waste removal every three to four weeks [10]. Longer retention of wastewater in septic tanks may cause sludge solidification and prevent their efficient emptying. The sewage from septic tanks differs from the domestic sewage transported via sewage systems in terms of type of degree of pollution [11-13]. The high costs of septic tank emptying encourage inhabitants to considerably limit water use and this leads to a significant increase in the sewage pollution degree. Too long intervals between emptying the tanks rots the sewage and its composition is then similar to highly hydrated sediments. Due to anaerobic fermentation of organic pollutants the sewage gives off the unpleasant odor of hydrogen sulfide and its color is black-and-gray. The sewage collected from the septic tanks is supplied to a collective wastewater treatment plant at different times and in irregular quantities [14, 15]. As the processes of biological purification are sensitive to substantial changes in both quantity and quality of sewage, the amount of sewage from the septic tanks added to the general sewage should be closely monitored [16-19]. An optimal solution for a WTP operator is to determine the percent of septic tank sewage that can be added to the sewage supplied by a sewage system to avoid significant changes in the concentration of pollutants in the total amount of sewage undergoing purification processes.

The aim of our study was to determine the optimal amount (percentage) of septic tank sewage that may be mixed with sewage transported via the sewage system without causing large fluctuations in organic pollutants content in the total amount of sewage undergoing treatment.

Material and Methods

The quantity and quality of the septic tank sewage and the sewage supplied via the sewage system were monitored from January 2013 to December 2014. During this period, 24 samples of each type of sewage were collected and analyzed at monthly intervals. The analysis covered:

- Quantity and quality of the sewage from septic tanks;
- Quantity and quality of the sewage supplied via the sewage system;
- Effects of quantity and quality of septic tank sewage on general quantity and quality of treated sewage.

The samples of the sewage supplied via the sewage system were collected from a control and measurement chamber located in front of the WTP, and the samples of septic tank sewage were collected at a sewage collection station. Both facilities were located in Wołowice, Czernichów commune, Małopolska region, Poland. The

sewage samples were collected as recommended in PN-ISO 5667-10:1997: "Water quality. Sampling. Guidance on sampling of wastewaters. Both types of sewage samples were used to determine COD and BOD₅. Values of these parameters were established using reference methods indicated by the binding Regulation of the Minister of Environment as of 18 November 2014 [20].

The samples of sewage from the sewage system and septic tank were collected at the same time (day and hour). The amounts of both types of sewage supplied to the WTP were recorded on sampling days.

The investigated sewage system, located in a typical rural commune, is 42 km long and its diameter ranges from 200 to 315 mm. It serves about 1,600 inhabitants and includes 350 house drains. The collective sewage system serves nearly 30% of residential buildings. The remaining residents use on-site wastewater treatment systems or septic tanks, from which the sewage is delivered to the collective wastewater treatment plant.

Results and Discussion

Analysis of organic pollutants in the sewage transported via the sewage system indicated that mean COD and BOD₅ were characteristic and typical of domestic waste [21, 12-13]. Mean BOD₅ in the sewage system transporting sewage was 235.9 mg O₂·dm⁻³. No significant differences between minimum and maximum value of this parameter were found, as evidenced by the low coefficient of variation (0.17). Mean COD of 356.8 mg O₂·dm⁻³ was also typical for domestic waste. Coefficient of variation was also low and amounted to 0.18. The values of organic pollution indicators were much higher in the sewage transported by vacuum trucks than in the sewage transported via the sewage system. Mean BOD₅ in the septic tank sewage was 3157.5 mg O₂·dm⁻³. It ranged from 1,560.0 to 4,210.0 mg O₂·dm⁻³, and the coefficient of variation was 0.21. COD values in this type of sewage were also very high. Mean COD in the septic tank sewage was 5,795.8 mg O₂·dm⁻³. It ranged from 2,880.0 to 7,600.0 mg O₂·dm⁻³, and the coefficient of variation was 0.20. Such a high concentration of organic pollutants in the septic tank sewage is due to a number of factors discussed in the Introduction. The values of investigated indicators in both types of sewage are presented in Table 1.

The mean amount of sewage transported via the sewage system on the sampling days was 212.9 m³·d⁻¹. Over the study period, no considerable fluctuations in the amount of this type of sewage were recorded, as evidenced by low standard deviation (20.7 m³·d⁻¹) and coefficient of variation of 0.10. The minimum amount of sewage was 32.9 m³·d⁻¹ lower than the average, and maximum amount was by 37.1 m³·d⁻¹ higher than the average. The amount of sewage supplied by vacuum trucks from non-sewered areas of the commune ranged from 5.0 to 28.0 m³·d⁻¹, with a mean of 14.8 m³·d⁻¹. The amount of supplied sewage was highly irregular, as evidenced by a standard deviation

Table 1. Characteristics of organic pollutants in the sewage supplied by the sewage system and vacuum trucks.

Index [Unit]	Statistics						
	Type of sewage	Mean [mg·dm ⁻³]	Median [mg·dm ⁻³]	Min. [mg·dm ⁻³]	Max. [mg·dm ⁻³]	Standard deviation [mg·dm ⁻³]	Coefficient of variation [-]
BOD ₅	sewage system	235.9	234.5	175.0	310.0	31.9	0.17
COD		356.8	372.5	230.0	450.0	65.3	0.18
BOD ₅	septic tanks	3157.5	3235.0	1560	4210	657.2	0.21
COD		5795.8	5980.0	2880.0	7600.0	1150.4	0.20

of 6.7 m³·d⁻¹ and high coefficient of variation amounting to 0.45. Analysis of the total amount of treated sewage revealed that the septic tank sewage accounted for 6.4% of the total sewage amount. However, this parameter was prone to considerable fluctuations of from 2.6% to 11.5%. Considerable variations in the percentage of the septic tank sewage in total amount of sewage was confirmed by standard deviation of 2.6% and coefficient of variation of 0.4. Typical amounts of sewage transported via the sewage system and by vacuum trucks are presented in Table 2.

The data on COD and BOD₅ and the amount of the sewage system and septic tank sewage were used to calculate the values of these indicators in the mixture of sewage undergoing treatment. This was performed using a weighted average represented by the following formula:

$$S_x = \frac{W_1 \cdot Q_1 + W_2 \cdot Q_2}{Q_1 + Q_2} [mg \cdot dm^{-3}] \tag{1}$$

...where S_x is the value of the indicator in the sewage mixture (mg·dm⁻³), W₁ is the value of the indicator in the sewage system sewage (mg·dm⁻³), W₂ is the value of the indicator in the septic tank sewage (mg·dm⁻³), Q₁ is the amount of sewage system sewage (dm³·d⁻¹), and Q₂ is the amount of septic tank sewage (dm³·d⁻¹).

BOD₅ in the sewage mixture, calculated on the basis of weighted average (1), ranged from 258.5 to 799.0 mg O₂·dm⁻³. Therefore, the difference between minimum and maximum value was 540.5 mg O₂·dm⁻³. The values of COD in the sewage mixture were also highly variable. Its minimum and maximum were 376.1 and 1310.5 mg O₂·dm⁻³, respectively, and the difference between minimum and maximum was 934.4 mg O₂·dm⁻³. The indicators of organic pollution in the mixture of sewage undergoing treatment suggested that large fluctuations in

their value might negatively affect biological treatment processes. The values of investigated indicators of organic pollution (COD and BOD₅) in the total amount of treated sewage are presented in Figs 1 and 2.

Biological treatment is effective when the amount of supplied sewage and the degree of its pollution are stable and their fluctuations are low [22, 23]. In this study, the amount of sewage reaching the wastewater treatment plant via the sewage system and the content of organic pollutants were stable and characterized by low variability. Large fluctuations in the level of organic pollutants in the sewage mixture were due to the septic tank sewage. Although the percentage of this type of sewage in total amount of treated sewage was low and ranged from 2.6% to 11.5%, BOD₅ and COD in the septic tank sewage were very high. Mean BOD₅ in mixed sewage was 476.8 mg O₂·dm⁻³, and minimum and maximum values were 258.5 and 799.0 mg O₂·dm⁻³, respectively. Mean COD was 786.5 mg O₂·dm⁻³, and extreme values ranged from 376.1 to 1310.5 mg O₂·dm⁻³. Both indicators were highly variable in the mixed sewage undergoing treatment. As mentioned above, this may negatively affect treatment effectiveness. This is why the next step of the study was to determine optimum share of septic tank sewage that does not cause large fluctuations in organic pollution levels, and ensures that the composition of the treated sewage is similar to typical domestic sewage. Characteristic values of BOD₅ and COD are displayed in Figs 1 and 2.

The data on the share of both types of sewage in total amount of sewage and on organic pollution (BOD₅ and COD) were used to carry out an analysis of partial correlation. The aim of this analysis was to determine the effect of two independent variables, i.e., the share and value of the specific indicator on the value of this parameter in the mixed sewage undergoing treatment.

Table 2. Amount of sewage transported via the sewage system and by vacuum trucks.

Type of sewage	Statistics					
	Mean [m ³ ·d ⁻¹]	Median [m ³ ·d ⁻¹]	Min. [m ³ ·d ⁻¹]	Max. [m ³ ·d ⁻¹]	Standard deviation [m ³ ·d ⁻¹]	Coefficient of variation [-]
sewage system	212.9	209.5	180.0	250.0	20.7	0.10
septic tanks	14.8	13.0	5.0	28.0	6.7	0.45

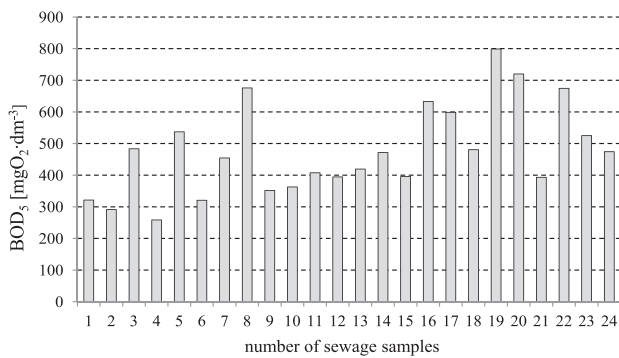


Fig. 1. Weighted average for BOD_5 in the mixture of sewage system and septic tank sewage.

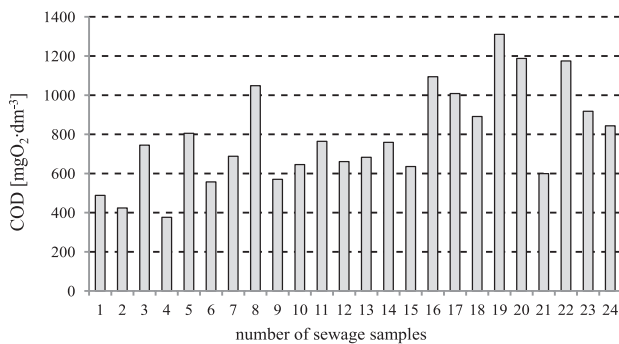


Fig. 2. Weighted average for COD in the mixture of sewage system and septic tank sewage.

Partial correlation analysis for BOD_5 revealed that the value of this parameter in the mixed sewage was affected by both the amount of septic tank sewage (%) and BOD_5 in this type of sewage. However, partial correlation results suggest that BOD_5 in the mixed sewage was to a greater extent affected by the percentage of septic tank sewage than by BOD_5 in this type of sewage. The effect of percentage share of septic tank sewage on BOD_5 in the sewage mixture amounted to $R_c = 0.93$, and the influence of BOD_5 in the septic tank sewage on BOD_5 in the total amount of sewage equaled to $R_c = 0.71$. According to a scale described by Stanisiz [24], the first correlation is nearly perfect and the second is very high. The significance of the resulting correlation coefficients was determined using Student t test for a significance level of $\alpha = 0.05$. The correlations proved to be significant in both cases.

COD was found to be more dependent on the percentage of septic tank sewage in the sewage mixture, and correlation of these two parameters was $R_c = 0.94$. The value of COD in the sewage mixture depended on its value in the septic tank sewage that was $R_c = 0.73$. According to the above-mentioned scale, the correlations of these variations were nearly perfect and very high. The levels of significance of the resulting correlation coefficients were determined using Student t-test for significance of $\alpha = 0.05$. Both correlations were found to be significant.

The nomograms presented in Figs 3 and 4 were prepared to determine the optimum amount of septic tank

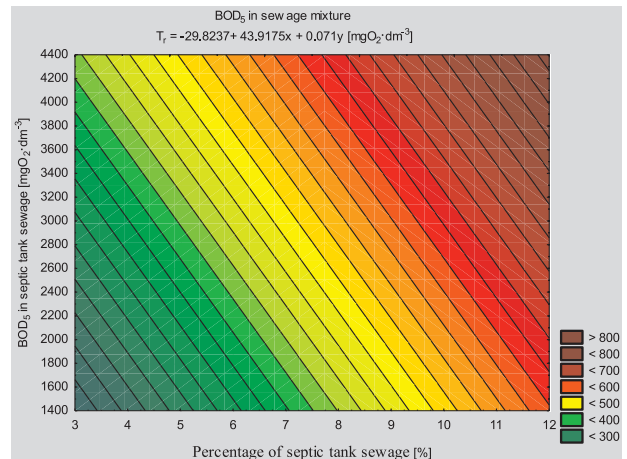


Fig. 3. Nomogram for forecasting BOD_5 in the sewage mixture based on the percentage of septic tank sewage and its BOD_5 value.

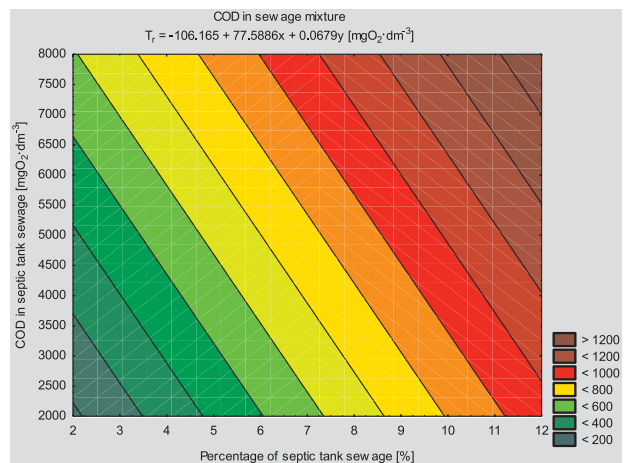


Fig. 4. Nomogram for forecasting COD in the sewage mixture based on the percentage of septic tank sewage and its COD value.

sewage that would not cause large fluctuations in organic pollution, expressed by means of BOD_5 and COD, in the total amount of treated sewage. The nomograms can be used to predict (forecast) the values of specific parameters in the sewage mixture, depending on the parameter value in the septic tank sewage (Y axis) and the percentage of the septic tank sewage (X axis). As mentioned before, stability of biological processes might be affected by even small fluctuations in the concentration of pollutants supplied with the sewage. For the purpose of this study, optimum BOD_5 and COD levels were assumed as their medians, i.e., $463.0 \text{ mgO}_2 \cdot \text{dm}^{-3}$ for BOD_5 and $751.8 \text{ mgO}_2 \cdot \text{dm}^{-3}$ for COD.

For example, if we assume stable values of both parameters in the septic tank sewage, where BOD_5 median was $3235.0 \text{ mgO}_2 \cdot \text{dm}^{-3}$ and COD median was $5980 \text{ mgO}_2 \cdot \text{dm}^{-3}$, T_R equations of partial correlation suggest that the optimum share of septic tank sewage in total amount of treated sewage is about 5%. Therefore, the amount of the septic tank sewage supplied by

vacuum trucks to the investigated WTP plant with mean daily treatment capacity of 230 m³ should be around 11.5 m³·d⁻¹. Supplying this amount of septic tank sewage to the WTP will allow for stabilization of both organic pollution indicators (BOD₅ and COD) and hydraulic fluctuations. When following sewage system expansion, the amount of sewage supplied via this channel would increase and the simulation should be adapted accordingly.

Conclusions

1. The level of organic pollutants, expressed by BOD₅ and COD, was many times higher in the septic tank sewage than in the sewage transported via the sewage system.
2. Mean values of these indicators in the septic tank sewage were 3,157.5 mg O₂·dm⁻³ for BOD₅ and 5,795.8 mg O₂·dm⁻³ for COD. Moreover, these indicators were highly variable and ranged from 1,560.0 to 4,210.0 mg O₂·dm⁻³ for BOD₅ and from 2,880.0 to 7,600.0 mg O₂·dm⁻³ for COD.
3. Partial correlation analysis showed that variability and fluctuations of organic pollution in the sewage mixture depended to a greater extent on the percentage of septic tank sewage than on the level of organic pollution in this sewage.
4. With basic data on the quantity and quality of the sewage transported via the sewage system and septic tank sewage, the optimum percentage of septic tank sewage may be determined for any treatment system. In the analyzed wastewater treatment plant the percentage of septic tank sewage in the total volume of treated sewage should be around 5%.

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