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NITROGEN COMPOUNDS IN EFFLUENTS FROM A SEPTIC TANK

The paper presents the results of long-term studies on the concentrations of total nitrogen and ammonium nitrogen in a septic tank effluent. A statistical analysis concerning the sampling day and the season was performed. The mean concentration of total nitrogen in the effluent was 47±9 g N/m^3 and the mean concentration of ammonium nitrogen was 33±11 g N/m^3. Results on the cumulative distributions of total nitrogen and ammonium nitrogen in the outflow from the septic tank have also been presented.

1. INTRODUCTION

Septic tanks are basic devices used in domestic wastewater treatment plants. They are often called settling pits and are the first step in the sewage treatment process. According to the standard, domestic wastewater treatment plants are facilities that can serve up to 50 people. Research carried out by Marzec and Jóźwiakowski [1, 2] on several domestic wastewater treatment plants demonstrated that the lack of a septic tank negatively affected their operation and the efficiency of pollutant removal. Septic tanks are single or multi-chamber containers with a continuous, slow flow of sewage, during which solid pollutants sink to the bottom and are slowly decomposed due to the action of anaerobic or facultatively anaerobic bacteria. As a result of this decomposition, more stabilized organic compounds and gases are formed: hydrogen sulfide, carbon dioxide, and methane. Hydrogen sulfide combines with metal ions in the sludge to form insoluble sulfides, which causes significant elimination of foul odors from settling tanks.

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A septic tank is most often the first component of an on-site wastewater treatment plant, treating sewage mainly by sedimentation and flotation. In the septic tank, anaerobic treatment takes place, but due to the low temperature inside, biological treatment is very slow. The effectiveness of wastewater treatment affects the effectiveness of the successive stages of treatment, among others, of biological reactors. On-site wastewater treatment plants are popular in non-urbanized areas, where for economic and technical reasons it is not advisable to build a collective sewerage system and wastewater treatment system. In Poland, since 2010, there has been a sudden increase in the number of registered on-site wastewater treatment plants. By the end of 2022, they numbered about 344 thousand, of which about 293.2 thousand were installed in rural areas. In 2022, 26 949 new installations were reported, of which 21 484 were installed in rural areas.

This research aimed to provide information on the seasonal and daily variability of sewage quality in the context of nitrogen forms at the outflow from the septic tank. A large amount of collected data will facilitate the design of different parts of the on-site wastewater treatment plants.

2. MATERIALS AND METHODS

The periodic repeatability of the determined concentrations of nitrogen compounds ascending in the outflow of the septic tank (dependent on the season or day of the week) was investigated. The septic tank was filled with raw sewage from a single-family house, inhabited by 5 people (four adults and one child). The test septic tank was cuboid in shape with the following dimensions: width 0.80 m, length 1.90 m, height to the bottom of the inlet (DN please explain 160 mm) 1.35 m, height to the bottom of the outlet (DN 160 mm) 1.30 m. Its capacity was 2 m^3.

An outlet filter was attached to the outlet, filled with the material absorbing part of the suspended solids. The mean sewage flow was 0.83 m^3/day. The septic tank was emptied of the accumulated sludge and floating scum once a year. The analyses of the quality of the septic tank effluent consisted of several series of measurements, conducted by the staff of the Department of Hydraulic and Sanitary Engineering of the Poznań University of Life Sciences.

The concentration of total suspended solids (TSS) was measured by the direct weight method (196 results), 5-day biochemical oxygen demand (BOD_5) was determined by respirometry (188 results), dichromate chemical oxygen demand (COD) was determined by the standard method with a photometer reading (149 results) [3], and ammonium (NH_4^+-N) and total nitrogen (N_{tot}) concentrations were determined by the colorimetric method (191 and 156 results, respectively) using a Merck NOVA 60 photometer.

The measured values were grouped according to the days working of the week and seasons (spring 21.03–21.06, summer 22.06–23.09, autumn 24.09–21.12, winter – 22.12

–20.03) to check the quality of the effluent depending on time. Statistical analysis was performed using the program Statistica, with the Shapiro-Wilk test. The Kruskal–Wallis non-parametric test was used to test the differences between the means of several independent trials. The Wilcoxon test for multiple comparisons was used to evaluate the differences between independent variables (for seasons or days of the week). To present the probability of occurrence of a given concentration of total nitrogen and ammonium nitrogen along with the lower values, the curves using the Weibull distribution model were determined.

The Weibull model is a suitable method to evaluate the reliability of a system concerning the imposed requirements [4]. The Weibull probability distribution is based on the probability density function using three parameters

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

where x is the pollution index for treated wastewater, b is the scale parameter, c is the shape parameter and θ is the location parameter.

For the Weibull distribution, the complement of the cumulative distribution function to one ($F(x)$) is the reliability of the distribution

$$F(x)=1-\exp\left(\frac{(x-\theta)^{c}}{b}\right) \tag{2}$$

Parameters of the Weibull distribution are estimated using the maximum likelihood method, with the distribution fitted to empirical data by the Hollander–Proschan test [5, 6] (Table 1). Statistical calculations were performed using the Statistica ver. 13.3 program.

Table 1

Distribution parameters and fit measures for the Weibull model

Index	Distribution parameters		Hollander–Proschan test	
	Shape	Scale	Test value	p
N_{tot}	4.4166	51.344	0.552940	0.58030
NH_4^+-N	2.2767	36.657	–0.655742	0.51199

The amount of organic carbon was determined based on the redox chemical reaction of the oxidation of organic substrate with respect to COD. The general formula of the organic substrate is $C_{18}H_{19}O_9N$.

$$C_{18}H_{19}O_9N + 17.5O_2 + H^+ \rightarrow 18CO_2 + 8H_2O + NH_4^+ \tag{3}$$

$$\frac{17.5M_{O_2}}{118M_C} = \frac{560}{216} = 2.593 \text{ g } O_2/\text{g } C_{org} \rightarrow \text{COD 1 g C} = 2.593 \text{ g } O_2 \quad (4)$$

Based on the above calculations 1 g COD contains 0.386 g C.

3. RESULTS AND DISCUSSION

Concentrations of pollutants in the septic tank effluent were within the range given in the literature (Table 2). The values obtained for BOD_5, COD, and total suspended solids (TSS) demonstrated the high removal efficiency of the device. Table 2 presents characteristics of the septic tank effluent (TSS, BOD_5, COD) since organic compounds affect nitrogen transformation (nitrification (CO_2) and denitrification (C_{org})).

Table 2

Pollution indicator values obtained for the septic tank in question

Parameter	Number of measurements	Mean	Range	Literature data		
				Range of median [7]	Mean [8]	Range of mean [9]
TSS, g/m^3	196	43±3	0–239	28–192 (61)	202±67	–
BOD_5, g O_2/m^3	188	108±3	40–220	44–833 (216)	193±40	–
COD, g O_2/m^3	149	186±4	94–387	201–944 (389)	627±159	–
NH_4^+-N, g N/m^3	191	33±11	26–38	25–112 (53–56*)	84±15	34±7 (21–53)
N_{tot}, g N/m^3	156	47±9	19–80	27–119 (63. 64*)	101±21	46±3 (36-60)

* – mean value.

The range of total nitrogen variability (19–80 g N/m^3) is narrower and the range of extreme concentrations is slightly lower than those obtained elsewhere (27–119 g N/m^3) [7], or (26–124 g N/m^3) [15], while the mean of 47±9 g N/m^3 was slightly lower than those found in literature: 64±3 g N/m^3 [7] or 58±3 g N/m^3 [10]. However, the mean value and the range are very close to those presented in the literature [9].

The concentration of nitrogen compounds in the septic tank effluent according to different sources is presented in Table 3. Nitrogen in raw sewage occurs mainly as organic N and ammonium. The conversion of organic nitrogen (especially urea) to ammonium nitrogen (ammonification) under anaerobic conditions is rapid [10]. Lowe et al. [10] found that ammonium nitrogen constitutes 60% of total nitrogen in a septic tank effluent. McCray et al. [11] reported that 75–85% of the Kjeldahl nitrogen in a septic tank effluent is ammonium nitrogen, while Crites and Tchobanoglous [12] gave a figure of 60%. The above data suggest that the content of nitrogen depends on the construction of the septic tank and the source of sewage.

Kuczewski [13] investigated the concentration of total nitrogen and ammonium nitrogen in each chamber of a three-chamber septic tank. In the first chamber, the mean concentration of ammonium nitrogen was 60±10 g N/m^3 (range 43.8–76 g N/m^3); in the second chamber it was similar – 59±10 g N/m^3 (range 41.5–79.5 g N/m^3) and in the third one there was a decrease to 49±9 g N/m^3 (range 40.9–71.5 g N/m^3). In the first chamber, the mean concentration of total nitrogen was 86±8 g N/m^3 (range 70.1–101.7 g N/m^3); in the next chamber, there was a decrease in the concentration of the total nitrogen, with a mean of 79±11 g N/m^3 (range 56.3–98.6 g N/m^3); and in the last chamber, a decrease in the concentration of the total nitrogen was observed with a mean of 70±8 g N/m^3 (range 63.5–84.1 g N/m^3). The above data indicate double-digit removal of nitrogen in a septic tank.

Table 3

Mean and range of concentrations of nitrogen in effluent of the septic tank according to different sources [g N/m^3]

TKN	NH_4^+-N	NO_2^--N	NO_3^--N	N_{tot}	Reference
54±3 (27–94)	37±2 (0–96)	–	0.82±0.28 (0–10.3)	– (26–124)	[10]
–	109±20 (65–148)	0,23±0.09 (0.01–0.39)	1.13±0.9 (0.09–3.26)	129±25 (85–175)	[17]
– (19–53)	–	–	– (0.01–0.16)	– (40–100)	[18]
60* (33–171)	53* (25–112)	–	0.7* (0.1–7.1)	63* (27–119)	[7]
–	84±15	–	0.6±0.1	101±21	[8]
53±18 (30–70)	34±7 (21–53)	–	0.023±0.07 (0.013–0.035)	46±3 (36–60)	[9]

* – median value.

For pre-treated sewage flowing out of the septic tank, Micek et al. [14] obtained an average N_{tot} of 160 g N/m^3 (minimum 121 g N/m^3 and maximum 207 g N/m^3). Chmielowski [15] reported the mean concentration of total nitrogen 155 g N/m^3, Micek et al. [14] obtained a mean N_{tot} of 126 g N/m^3 (minimum 84 g N/m^3 and maximum 175 g N/m^3).

Jóźwiakowski [16] reported the concentration of NH_4^+-N in the outflow from the septic tank at the level of 90–140 g N/m^3 and the mean value of 112.7 g N/m^3. Chmielowski [15] reported the mean concentration of NH_4^+-N pre-treated sewage flowing out of the septic tank as 109 g N/m^3 (minimum 52 g N/m^3, maximum 157 g N/m^3). Micek et al. [14] obtained that the mean value of ammonium nitrogen in the outflow from the septic tank was 136 g N/m^3 (minimum 111 g N/m^3 and maximum 172 g N/m^3).

The studies presented by Lowe et al. [7] showed that the concentrations of total nitrogen in raw sewage differed markedly on different days of the week. The highest values were obtained on different days, depending on the area from which the results came (for example, Thursday and Friday in Colorado and Saturday and Sunday in Florida). Simultaneously the concentrations of nitrogen in the septic tank effluent were relatively stable regardless of the source of the data. An association between the concentration of nitrogen in raw sewage and water consumption was also noted.

According to Jóźwiakowski [16], the concentration of nitrite nitrogen in the sewage pre-treated after the septic tank is low and does not exceed 1.0 g N/m^3. Pawęska and Kuczewski [19] report that the combined concentration of nitrite NO_2^--N and nitrate NO_3^--N nitrogen was 0.62 g N/m^3. According to research by Niżyńska [20], the exploitation of leaking septic tanks and cesspits may cause an increased concentration of nitrates in groundwater. They are short-term forms of nitrogen found in low concentrations in pre-treated sewage in septic tanks. This is confirmed by the studies carried out on a single-chamber septic tank, where the author obtained the mean value of nitrite nitrogen (NO_2^--N) concentration at the level of 0.01 g N/m^3. Jóźwiakowski [16] measured the concentration of NO_2^--N in the outflow from the septic tank from 0.115 to 0.540 g N/m^3 and the mean value was 0.191 g N/m^3. In a study by Micek et al. [14], the authors obtained a mean NO_2^--N concentration of 0.31 g N/m^3 (minimum 0.03 g N/m^3, maximum 1.17 g N/m^3).

Chmielowski [15] found that the mean concentration of nitrate nitrogen in sewage flowing out of the septic tank was 1.82 g N/m^3. This result proves the prevalence of anaerobic conditions in the septic tank. Jóźwiakowski [16] reported NO_2^--N in the outflow from the septic tank at the level from 0.11 to 2.11 g N/m^3 and the mean value of 0.42 g N/m^3. In a study by Micek et al. [14], the authors obtained the mean value of NO_3^--N at the level of 1.97 g N/m^3 (minimum 0.09 g N/m^3, maximum 5.7 g N/m^3). The measured range of concentrations of ammonium nitrogen in the present paper is much narrower (36–38 g N/m^3) than obtained by other authors: 25–112 g N/m^3 [7] or collected in the report [10] based on literature data (0–96 g N/m^3) but similar to that presented in [9] (21–53) g N/m^3. In the present work, the mean NH_4^+-N concentration of 33±11 g/m^3 was lower than 56±2 g N/m^3 in [7], or 44±3 g N/m^3 in [10], close to 34±7 g N/m^3 in [9].

Mean total nitrogen concentrations in the septic tank effluent, taking into account seasons and days of the week, together with statistical parameters, are given in Tables 4 and 5 and shown in Figs. 1 and 3. The lowest values were obtained during summer and the highest in winter, which may be related to the higher water consumption in summer and lower in winter [7, 21].

Table 4

Mean total nitrogen concentrations together
with statistical parameters in the septic tank effluent with seasons

Parameter	Season			
	Spring	Summer	Autumn	Winter
Number of measurements	56	16	38	46
Range, g N/m^3	26–78	19–67	27–80	28–77
IQR, g N/m^3	40–52	31–42	41–51	42–56
Mean, g N/m^3	47±8	39±9	46±7	50±9
Median, g N/m^3	47	37	45	49

IQR – interquartile range: difference between first and third quartile.

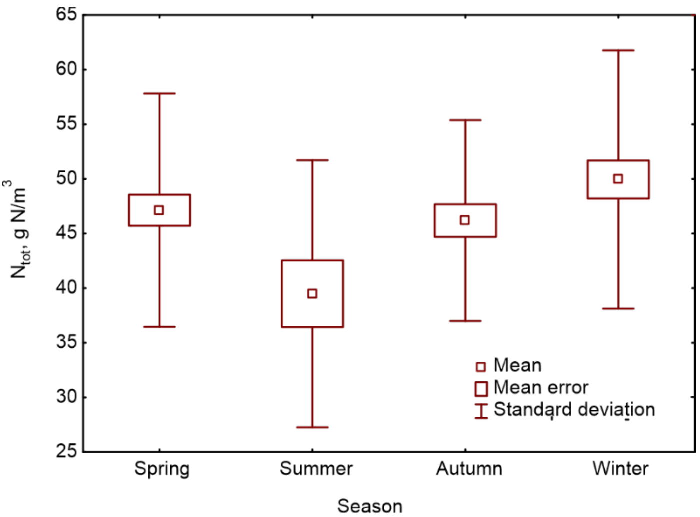

Fig. 1. Mean total nitrogen concentration in septic tank effluent by seasons

Table 5

Mean total nitrogen concentrations in the septic tank effluent
and statistical parameters during the week

Parameter	Day of the week				
	Monday	Tuesday	Wednesday	Thursday	Friday
Number of measurements	20	49	32	27	31
Range, g N/m^3	19–67	27–78	28–70	29–80	26–62
IQR, g N/m^3	40–50	39–52	43–58	43–54	37–49
Mean, g N/m^3	45±8	46±9	50±9	50±9	44±7
Median, g N/m^3	44	44	50	47	43

IQR – interquartile range: difference between first and third quartile.

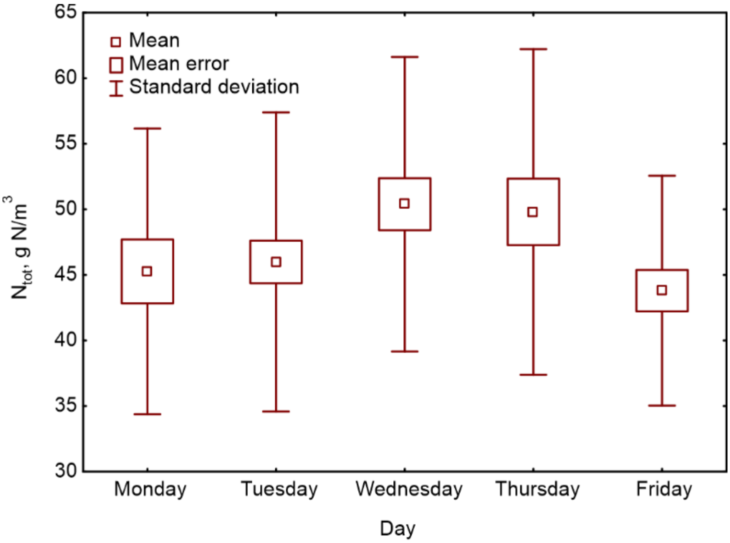

Fig. 2. Mean total nitrogen concentration in septic tank effluent by days of a week

In a study carried out on two three-chamber and two four-chamber septic tanks located in the Roztocze National Park in Poland, the authors found a low efficiency of nitrogen compound removal [17]. None of the septic tanks provided the effective elimination of biogenic compounds. In most cases, the concentrations of total nitrogen and phosphorous in primary sewage were higher than in raw sewage, suggesting that these elements were released from the sewage sludge during treatment [17]. Research carried out by Jóźwiakowski [16] on two septic tanks shows that the septic tanks provide little efficiency in removing biogenic compounds. Paluch et al. [22] observed that during the flow of sewage through a three-chamber septic tank, the concentration of organic nitrogen decreases along with the increase in the content of ammonium nitrogen. The studies carried out on two septic tanks also showed poor total nitrogen removal in these tanks, i.e., at the level of 16.5% [16]. Other literature sources also indicate low removal efficiencies for total nitrogen, e.g., as low as 5.9% [8]. Nitrogen in organic form can be accumulated as organic matter in the sludge which accumulates at the bottom of the septic tank. Under anaerobic conditions, some of the organic nitrogen may convert to ammonium. Microorganisms assimilate nitrogen in the ammonium form, which overall leads to a small reduction in total nitrogen, reported in the literature.

A significant difference in the mean total nitrogen concentration between summer and winter was also found in the statistical test, while no difference has been found by Lowe et al. [7]. Concerning the week, the highest concentrations of total nitrogen were obtained on Wednesday and Thursday, but they did not differ statistically significantly from the values obtained on the other days. The above was confirmed by Lowe et al. [10]; fluctuations in total nitrogen concentration in treated sewage during the week were small, although these studies showed variability in total nitrogen concentration in raw sewage (in 2 out of 3 regions there was an inverse correlation with water consumption).

The highest mean values for ammonium nitrogen were observed in autumn; the differences between the seasons were small. Lowe et al. [7] also showed no difference between these values depending on the season. The statistical tests did not show any significant difference between the means. During the week, the highest concentrations were observed on Monday and Wednesday, and the lowest on Friday. There was a statistically significant difference between Monday, Wednesday and Friday (Tables 6 and 7 and Figs. 3 and 4.

Table 6

Mean ammonium nitrogen concentrations
in the septic tank effluent and statistical parameters

Parameter	Season			
	Spring	Summer	Autumn	Winter
Number of measurements	70	18	49	54
Range, g N/m^3	1–85	10–61	5–92	1–70
IQR, g N/m^3	23–43	26–34	28–42	20–39
Mean, g N/m^3	33±12	31±9	35±9	31±12
Median, g N/m^3	70	18	49	54

IQR – interquartile range: difference between first and third quartile.

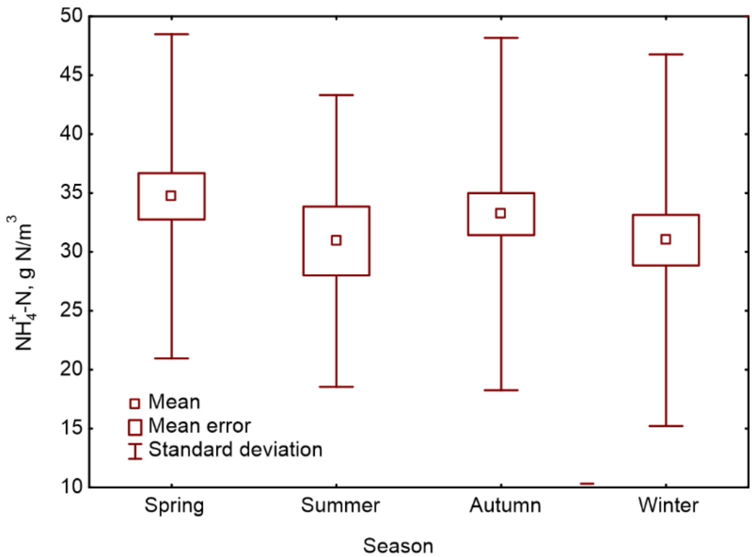

Fig. 3. Mean concentrations of ammonium nitrogen
in septic tank effluent by seasons

Table 7

Mean values of ammonium nitrogen concentration
and statistical parameters for the septic tank effluent during the week

Parameter	Day of the week				
	Monday	Tuesday	Wednesday	Thursday	Friday
Number of measurements	23	53	44	36	35
Range, g N/m^3	16–72	1–92	3–65	6–70	5–53
IQR, g N/m^3	32–43	24–40	29–47	23–40	19–32
Mean, g N/m^3	38±9	32±12	38±10	32±11	26±9
Median, g N/m^3	23	53	44	36	35

IQR – interquartile range: difference between first and third quartile.

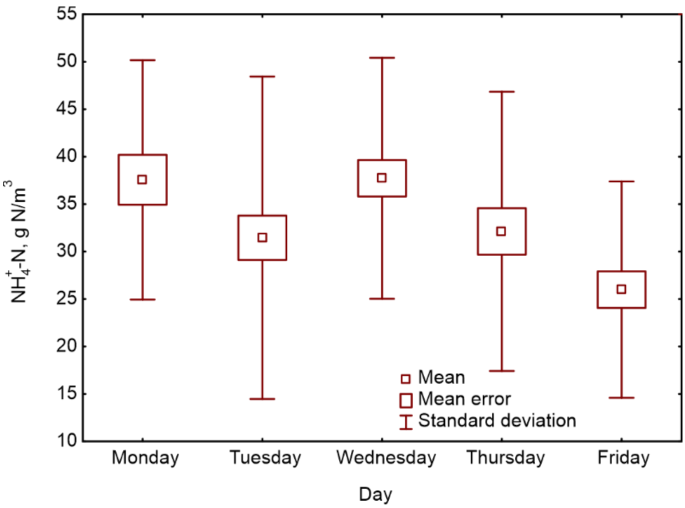

Fig. 4. Mean concentrations of ammonium nitrogen
in septic tank effluent by days of the week

Figures 5 and 6 show the results of the Weibull reliability analysis for the concentration of total and ammonium nitrogen in wastewater from the septic tank. Most of the concentrations of ammonium nitrogen ranged from 20 to 50 g N/m^3, and total nitrogen was in the range of 30–60 g N/m^3. The figures show the confidence limits with a probability of 95%. Concerning the mean concentration of total nitrogen (47 g N/m^3), 52% of measured values exceed it, which corresponds to 190 days during the year (Fig. 5). 47% of the measured concentrations of ammonium nitrogen exceed the mean value of 33 g N/m^3 which corresponds to 172 days during the year (Fig. 6).

More than twofold larger difference is observed in the amount of organic pollutants because the removal efficiency of the septic tank due to carbon compounds exceeds 50%. The value of organic carbon content was valculated based on Eqs. (3) and (4).

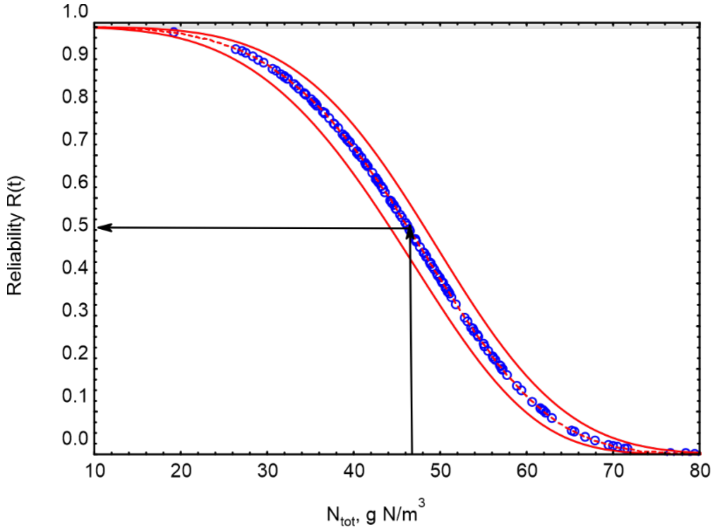

Fig. 5. Weibull reliability analysis for concentrations of total nitrogen in outflow from the septic tank

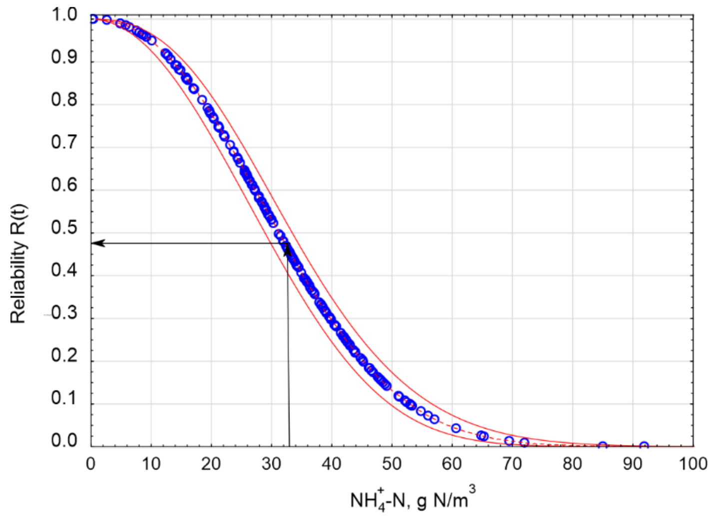

Fig. 6. Weibull reliability analysis for concentrations of ammonium nitrogen in outflow from the septic tank in question

The consequence is that the C/N ratio is smaller than for domestic wastewater (C/N ratio in the range of 1–6 [23]). The mean value of 1.562 (Table 8) was obtained for the wastewater in question. Such composition is characteristic of medium-sized sewers. Biodegradation problems may occur due to too little organic carbon available during this process. It is a good idea to limit the amount of air supplied to reduce the nitrification to the nitration stage, resulting in a lower demand for organic carbon (about 40%) for denitrifying bacteria [24].

Table 8

Carbon and nitrogen content in wastewater

Type of sewage	N_{tot} [g N/m^3]	COD [g O_2/m^3]	COD/N	C/N
Domestic wastewater	57	560	>5	>3
Studied wastewater after septic tank	47	186	4.046	1.562

4. SUMMARY

The study analyzes the content of nitrogen compounds in waste outflow from the septic tank, with the results of research conducted over 10 years. Based on the above information, the following conclusions can be drawn:

- The content of nitrogen compounds in the treated wastewater was within the range given in the literature. In the conducted research, the range of total nitrogen variability is slightly narrower, and a slightly lower range of extreme concentration was determined from total nitrogen than that reported in the literature.
- The difference in mean values obtained during the week is related to the way people live and work, so it is difficult to compare results from different sources. However, differences in particular seasons of the year are related to different water consumption in the summer and winter months.
- Susceptibility to biological treatment of sewage after the septic tank is unsatisfactory due to the low value of the C/N ratio (and COD/N ratio). For this reason, biodegradation problems may occur due to too little organic carbon available during biodegradation.
- Comparing the literature data on the contents of total nitrogen in raw wastewater and those examined in the present study, the difference is small, as only a few percent of nitrogen compounds are removed in the septic tank.
- The septic tanks are characterized by a relatively low efficiency in removing pollutants, especially biogenic pollutants, and therefore one of the following solutions can be used as the second stage of treatment: reactors with active sludge, sand filter with vertical flow, sand filter with horizontal flow, constructed wetland systems, biological bed, etc.
- In summary, septic tanks are basic and necessary elements of every domestic wastewater treatment plant. Their proper design will allow long and safe operation of the second stage of sewage treatment and thus will ensure high quality of treated sewage discharged into a receiver.

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