Removal of pollutants in wastewater treatment plants

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Abstract

Wastewater treatment plants (WWTPs), which operate due to the vital activity of microorganisms, often do not achieve high nitrogen and phosphorus removal from wastewater. Nitrogen and phosphorus compounds in treated wastewater enter surface water bodies and cause their eutrophication. The effective treatment of wastewater is essential for creating a sustainable environment. Three WWTPs were selected with similar effluent discharges (10 m^3/d) and the removal of pollutants was analyzed. Chemical analysis data of wastewater samples of WWTPs effluent was collected and evaluated for each quarter for 5 years (2017-2021). The results showed that 76.67% of the residual total phosphorus concentration, 1.67% of biochemical oxygen demand (BOD_7), and 25% of total nitrogen from all analyzed samples did not meet the requirements for treated wastewater. In order to achieve a higher level of removal of nitrogen and phosphorus compounds, additional tertiary treatment is recommended.

Keywords: wastewater, pollutants, removal, efficiency

I. INTRODUCTION

Biological wastewater treatment, which operates due to the vital activity of microorganisms, is the main method of domestic wastewater treatment. Wastewater treatment plants (WWTPs) with conventional technology do not always meet the stricter requirements for the quality of treated wastewater [1]. The main wastewater treatment process can not completely remove nitrogen (N) and phosphorus (P) compounds. Often WWTPs with low flow of wastewater release the higher residual concentrations of these compounds in the treated wastewater. Untreated or insufficiently treated wastewater pollutes the natural environment: land, soil, lakes, rivers, or other bodies of water and groundwater [2]. Nitrogen and phosphorus compounds in treated wastewater enter surface water bodies and cause their eutrophication. The concentration of nitrogen and phosphorus compounds is higher than normal in surface water bodies [3, 4]. Eutrophication threatens the supply of drinking water, recreation, and fish and wildlife habitats [5, 6]. The condition of many European water bodies is poor due to eutrophication [7]. The European water policy aims to achieve good ecological status (defined as a small deviation from near-natural conditions) in all rivers, lakes, coastal and intermediate waters by 2027 at the latest [8].

Three WWTPs were selected with similar effluent discharges (10 m^3/d) in order to find out the efficiency of pollutants removal from wastewater and determine the need for tertiary treatment of wastewater.

II. METHODS

Three WWTPs with a flow rate of 10 m^3 per day but with a population equivalent (PE) less than 10000 were selected in Lithuania.

The data of wastewater quality before and after wastewater treatment from real wastewater treatment systems were collected and evaluated for each quarter for 5 years (2017-2021), with a total of 20 wastewater samples per WWTP.

Chemical analysis data of wastewater quality consisted of pH, total suspended solids (TSS), chemical oxygen demand (COD), biochemical oxygen demand (BOD_7), ammonium nitrogen (NH_4-N), nitrate nitrogen (NO_3-N), nitrite nitrogen (NO_2-N), total nitrogen (TN), ortho-phosphate phosphorus (PO_4-P) and total phosphorus (TP) concentrations. The standard analytical methods were applied to analyze the parameters listed above: EN ISO 10523:2012; EN 872:2005; ISO 6060:2003; EN 1899-1:2000; ISO 7150-1:1998; ISO 7890-3:1998; EN 26777:1999; EN 25663-2000; EN ISO 6878-2004; EN ISO 6878-2005. Selected data were processed statistically by applying a confidence interval of 95 % and values of arithmetical average, maximum, minimum, median, and standard deviation were calculated.

Wastewater chemical analysis results were compared to requirements for the quality of treated wastewater in Lithuania (DLK): an instantaneous maximum permitted concentration is 23 mg/L for BOD_7; an instantaneous maximum permitted concentration is 2 mg/L for TP; an instantaneous maximum permitted concentration is 20 mg/L for TN. BOD_7, TP and TN removal efficiency from wastewater must reach 70-90%, 80% and 70-80%, respectively [9]. An analysis has been carried out to evaluate how much requirements for the quality of treated wastewater are met.

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III. RESULTS

A. Removal efficiency

The results of BOD_7 in treated wastewater from the first WWTP (1), the second WWTP (2), and the third WWTP (3) are shown in Figure 1.

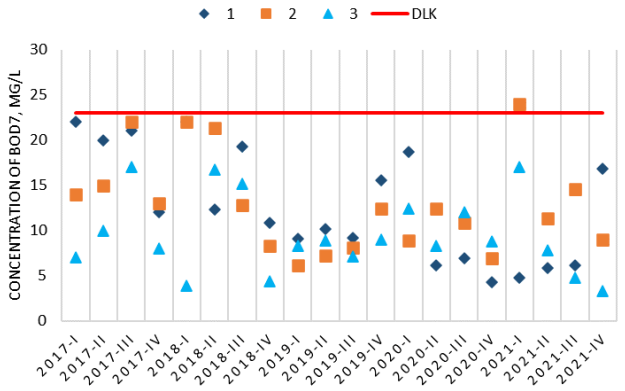

Figure 1. BOD_7 residual concentration compliance with the requirements (DLK)

The initial average concentration of BOD_7 before WWTPs was 400 mg/L.

The average concentration of BOD_7 in the treated wastewater in the first WWTP was 12.64 mg/L, the minimum - 4.26 mg/L, and the highest – 22 mg/L.

The average concentration of BOD_7 in the treated wastewater in the second WWTP was 13 mg/L, the minimum – 6.12 mg/L, and the highest – 24 mg/L.

The average concentration of BOD_7 in the treated wastewater in the third WWTP was 9.49 mg/L, the minimum – 3.32 mg/L, and the highest – 17 mg/L.

According to the BOD_7 indicator, all the WWTPs meet the requirements (Fig. 1). Only 1 unallowable concentration (24 mg/L) of BOD_7 was detected (1.67% of total samples).

The results of total nitrogen in treated wastewater from the first WWTP (1), the second WWTP (2), and the third WWTP (3) are shown in Figure 2.

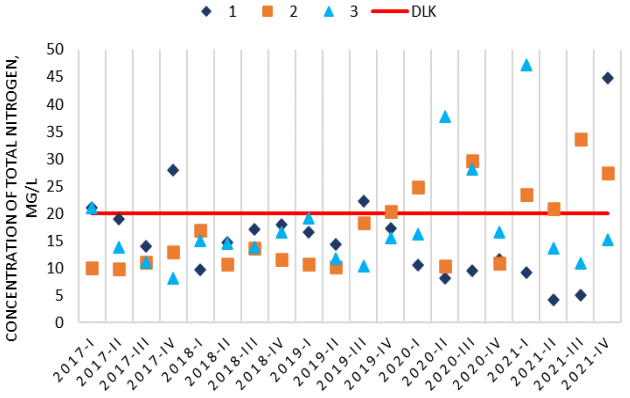

Figure 2. Total nitrogen residual concentration compliance with the requirements (DLK)

The initial average concentration of TN before WWTPs was 80 mg/L.

The average concentration of TN in the treated wastewater in the first WWTP was 15.73 mg/L, the minimum - 4.2 mg/L, and the highest – 44.8 mg/L.

The average concentration of TN in the treated wastewater in the second WWTP was 16.88 mg/L, the minimum – 9.9 mg/L, the highest –33.7 mg/L.

The average concentration of TN in the treated wastewater in the third WWTP was 17.81 mg/L, the minimum – 8.1 mg/L, the highest – 47.2 mg/L.

15 unallowable concentrations of TN were detected (25 % of total samples).

The results of total phosphorus in treated wastewater from the first WWTP (1), the second WWTP (2), and the third WWTP (3) are shown in Figure 3.

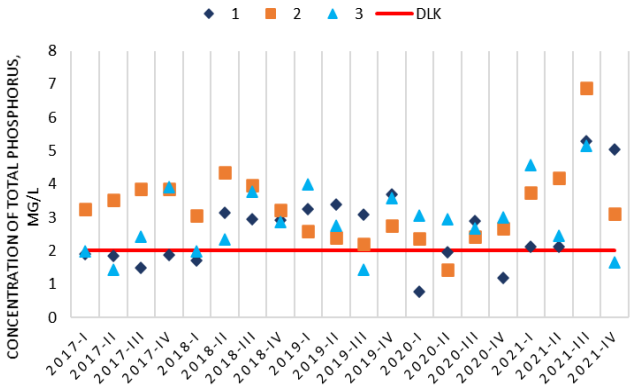

Figure 3. Total phosphorus residual concentration compliance with the requirements (DLK)

The initial average concentration of TP before WWTPs was 10 mg/L.

The average concentration of TP in the treated wastewater in the first WWTP was 2.63 mg/L, the minimum – 0.8 mg/L, and the highest – 5.29 mg/L.

The average concentration of TP in the treated wastewater in the second WWTP was 3.29 mg/L, the minimum – 1.43 mg/L, and the highest – 6.89 mg/L.

The average concentration of TP in the treated wastewater in the third WWTP was 2.9 mg/L, the minimum – 1.42 mg/L, and the highest – 5.15 mg/L.

46 unallowable concentrations of TP were detected (76.67 % of total samples).

The results of total phosphorus removal efficiency in the first WWTP (1), the second WWTP (2), and the third WWTP (3) are shown in Figure 4.

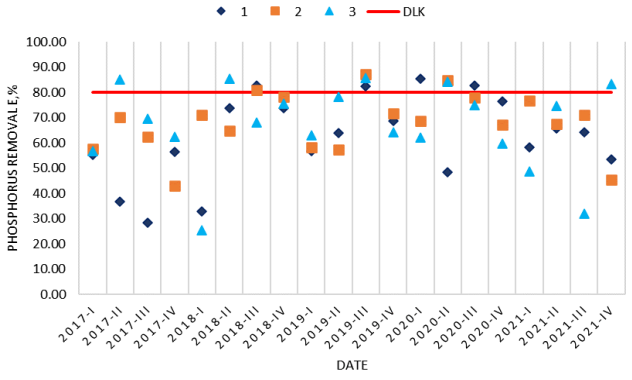

Figure 4. Total phosphorus removal efficiency compliance with the requirements (DLK)

The efficiency of TP removal was less likely to meet the requirements for the quality of treated wastewater: only 18.3 % met the requirements and 81.7 % did not.

It should be noted that the maximum permitted concentrations were exceeded by the quarterly average concentrations. Therefore, instantaneous concentrations could have been even higher.

B. Removal of nitrogen

Wastewater treated in conventional wastewater treatment plants with activated sludge has a low concentration of organic compounds, but high nitrate concentrations [10]. After biological wastewater treatment, nitrate nitrogen theoretically accounts for the majority of total nitrogen, because total nitrogen concentration in wastewater is reduced during biological treatment by nitrification (aerobic respiration: oxidation of ammonia to nitrates and nitrites) and denitrification (anoxic respiration: reduction of nitrates to gaseous nitrogen) [11].

Examining the data of wastewater treatment protocols for the selected period, the distribution of ammonium nitrogen and nitrate nitrogen in the concentration of total nitrogen was determined for each treatment plant.

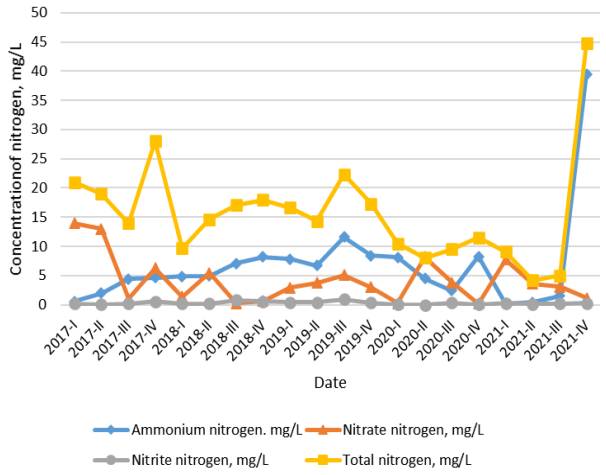

Figure 5. Distribution of ammonium nitrogen and nitrate nitrogen in the total nitrogen concentration in 1st WWTP

In Figure 5 can be seen, that in treated wastewater from the first WWTP ammonium nitrogen or nitrate nitrogen accounts for the majority of total nitrogen at a different quarter of the year. Also, the average percentage amount of ammonium nitrogen in the total nitrogen concentration was 43.4 % and the amount of nitrate nitrogen in the total nitrogen concentration was 27.1 %.

The average concentration of ammonium nitrogen in the treated wastewater in the first WWTP was 6.82 mg/L and the average concentration of nitrate nitrogen was 4.26 mg/L.

So, in most cases, the total nitrogen concentration consisted of ammonium nitrogen in the 1st WWTP.

In Figure 6 is shown, that in treated wastewater from the second WWTP ammonium nitrogen accounts for the majority of total nitrogen at a different quarter of the year. Also, the average percentage amount of ammonium nitrogen in the total nitrogen concentration was 68.2 % and the amount of nitrate nitrogen in the total nitrogen concentration was only 7.2 %.

The average concentration of ammonium nitrogen in the treated wastewater in the second WWTP was 11.52 mg/L and the average concentration of nitrate nitrogen was 1.21 mg/L.

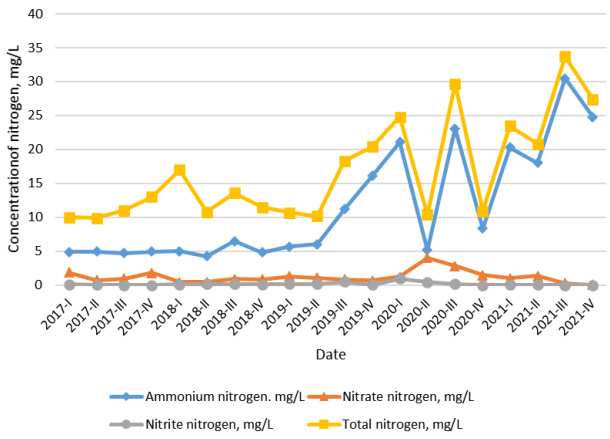

Figure 6. Distribution of ammonium nitrogen and nitrate nitrogen in the total nitrogen concentration in 2nd WWTP

So, in most cases, the total nitrogen concentration consisted of ammonium nitrogen in the 2nd WWTP.

In Figure 7 is shown, that in treated wastewater from the third WWTP ammonium nitrogen accounts for the majority of total nitrogen at a different quarter of the year. Also, the average percentage amount of ammonium nitrogen in the total nitrogen concentration was 59.6 % and the amount of nitrate nitrogen in the total nitrogen concentration was only 13.3%.

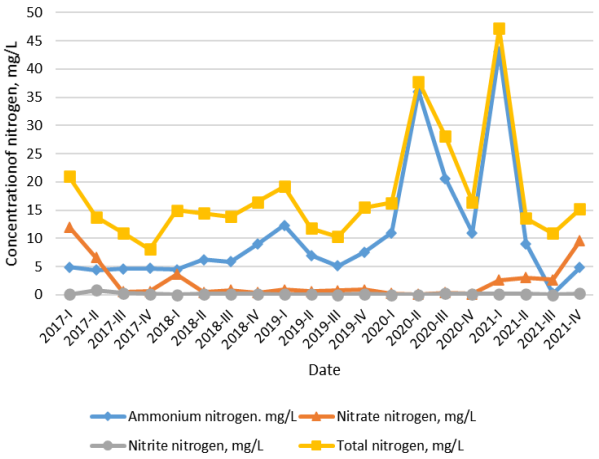

Figure 7. Distribution of ammonium nitrogen and nitrate nitrogen in the total nitrogen concentration in 3rd WWTP

The average concentration of ammonium nitrogen in the treated wastewater in the third WWTP was 10.61 mg/L and the average concentration of nitrate nitrogen was 2.37 mg/L.

So, in most cases, the total nitrogen concentration consisted of ammonium nitrogen in the 3rd WWTP.

Summarizing the nitrogen removal results, it can be said that a similar situation was found in three different WWTPs with the same flow rate - the concentration of ammonium nitrogen accounted for most of the total nitrogen concentration. These WWTPs have a problem with the nitrification process. It is important information for designing the tertiary wastewater treatment to achieve a higher level of removal of nitrogen compounds.

Obviously, before applying additional (tertiary) wastewater treatment, the composition of total nitrogen compounds in each treatment plant must be assessed.

C. Removal of phosphorus

When considering conventional phosphorus removal technologies, a few key factors must be taken into account. Firstly, there is the requirement to remove up to 80% of incoming TP load to meet the current discharge requirement of 2 mg/L. In conventional wastewater treatment plants, approximately 10% of total phosphorus can be removed during solids settling and 30% during the biological metabolism of microorganisms [12]. Consequently, phosphorus is removed inefficiently and an additional 40% removal of P is required.

The distribution of phosphate phosphorus in the concentration of total phosphorus was determined for each treatment plant.

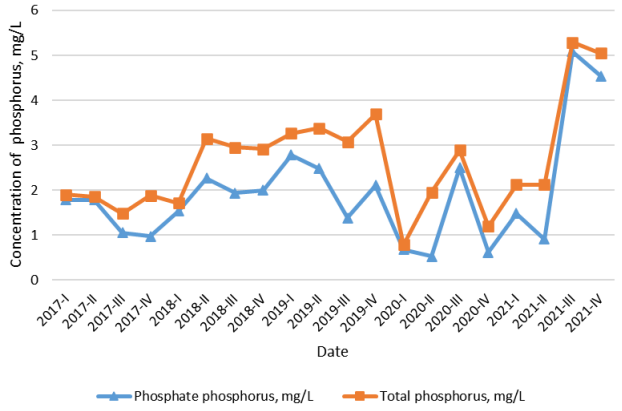

Figure 8. Distribution of phosphate phosphorus in the total phosphorus concentration in 1st WWTP

In Figure 8 can be seen, that in treated wastewater from the first WWTP the phosphate phosphorus accounts for the majority of the total phosphorus concentration. Also, the average percentage amount of phosphate phosphorus in the total phosphorus concentration was 72.9 %.

The average concentration of phosphate phosphorus in the treated wastewater in the first WWTP was 1.92 mg/L and the average concentration of total phosphorus was 2.63 mg/L.

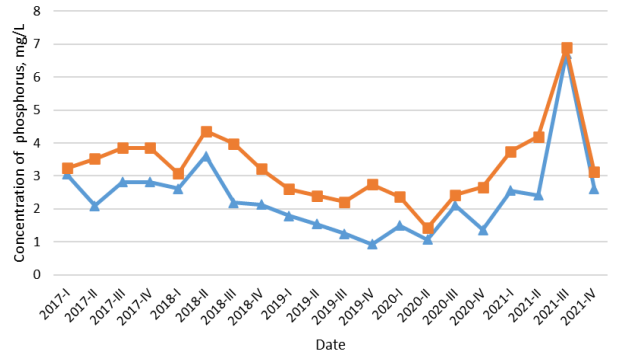

Figure 9. Distribution of phosphate phosphorus in the total phosphorus concentration in 2nd WWTP

In Figure 9 is shown, that in treated wastewater from the second WWTP the phosphate phosphorus accounts for the majority of the total phosphorus concentration. Also, the average percentage amount of phosphate phosphorus in the total phosphorus concentration was 71.6 %.

The average concentration of phosphate phosphorus in the treated wastewater in the second WWTP was 2.36 mg/L and the average concentration of total phosphorus was 3.29 mg/L.

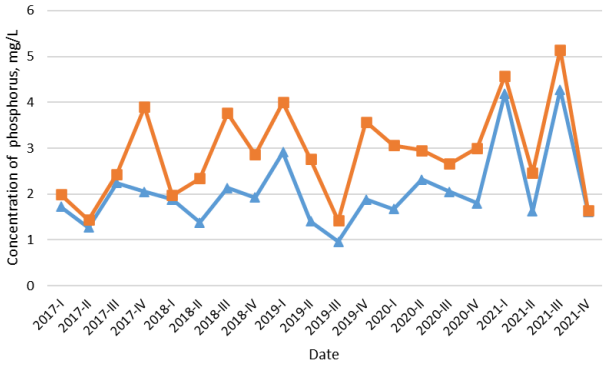

Figure 10. Distribution of phosphate phosphorus in the total phosphorus concentration in 3rd WWTP

In Figure 10 is shown, that in treated wastewater from the third WWTP the phosphate phosphorus accounts for the majority of the total phosphorus concentration. Also, the average percentage amount of phosphate phosphorus in the total phosphorus concentration was 71.2 %.

The average concentration of phosphate phosphorus in the treated wastewater in the third WWTP was 2.06 mg/L and the average concentration of total phosphorus was 2.90 mg/L.

It can be assumed, that the phosphate concentration of phosphates makes up the major part (about 70%) of total phosphorus. The orthophosphate (PO_4-P) is the most abundant form in domestic wastewater: it represents 60–85% of total phosphorus due to the hydrolysis of polyphosphates and organic phosphates [13].

In this study, it was found that the main pollutants in the wastewater, that cause eutrophication - nitrogen and phosphorus, were not removed effectively. In order to protect the environment around us, water resources, also to reduce eutrophication, it is necessary to install tertiary wastewater treatment plants, that will reduce residual concentrations of nitrogen and phosphorus compounds. It is recommended that tertiary wastewater treatment plants should not be expensive to install and operate, should be environmentally friendly, and be suitable for small and medium-sized wastewater treatment plants. Also, before applying tertiary wastewater treatment, the composition of wastewater pollutants in each treatment plant must be assessed.

IV. CONCLUSIONS

The results showed that 76.67% of the residual total phosphorus concentration, 1.67% of biochemical oxygen demand (BOD_7), and 25% of total nitrogen from all analyzed samples did not meet the requirements for treated wastewater. The efficiency of total phosphorus removal did not meet the requirements for the quality of treated wastewater in 81.7 % of cases. The results justified the need for tertiary treatment of wastewater in all three WWTP. In order to achieve a higher level of removal of nitrogen and phosphorus compounds, additional tertiary treatment is recommended.

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