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Article

Assessment of the efficiency of a municipal wastewater treatment plant from Romania. A case study

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Abstract
The present study was carried out to evaluate the efficiency of a municipal wastewater treatment plant (WWTP) that uses the biological treatment processes with activated sludge. The WWTP monitoring was carried out at the end of 2023, after the expansion and modernization stage, achieved during the period 2018-2023.The wastewater samples were collected from three important points of the wastewater treatment plant for four weeks, between October and November 2023. The physical-chemical parameters analyzed were: pH, chemical oxygen demand (COD), biochemical oxygen demand (BOD5), total suspended solids (TSS), volatile suspended solids (VSS), total nitrogen (TN), ammonia nitrogen (N-NH_4^+), nitrates (N-NO_3^-), total phosphorus (TP). The obtained results were very useful for checking the performance parameters of the sewage treatment plant.

Keywords: *wastewater treatment plant, wastewater, physical-chemical parameters*

INTRODUCTION

The wastewater is the result of domestic, industrial, and economic activities, sanitary services, and many other sources that are mainly found in the urban environment. The larger the population, the more the wastewater has a greater load of substances and pollutants that require greater attention to reduce the degree of pollution and implicitly the impact on the environment.

The municipal wastewater treatment plants are an important component in the context of the circular economy for the implementation of the 3R principles - reduction, reuse and recycling by reducing the load of wastewater that generates biogas byproducts - which can be used as fuel and the surplus sludge of the station that can be used as a soil improver. Since total nitrogen and total phosphorus are responsible for the eutrophication of surface waters and lakes into which the treated wastewater is discharged, it is imperative to find the most efficient method of removing them from wastewater.

Depending on the geographic location, demographics, climate, water resources, and available technology, wastewater treatment plants can vary in size, volume capacity of treated water, and operating systems. The models can be simpler but also more complex with different degrees of efficiency.

The wastewater can be classified as follows: domestic (wastewater discharged from residential and commercial establishments, including sanitation infrastructures and other household activities), industrial (wastewater from various industrial and / or commercial processes, other than domestic wastewater and storm water), urban wastewater (wastewater generated from domestic activities), infiltration (extraneous water entering the sewer system by indirect and direct methods), storm water (from precipitation, including meltwater from hail and snow); water which can infiltrate into the soil (groundwater), be stored on land surface (evaporate back into the atmosphere), or contribute to surface runoff) [1].

Wastewater treatment is an essential process that removes / reduces the concentration of contaminants or harmful pollutants from water so that the quality parameters comply with the normal discharge limits for treated effluents [2].

Conventional wastewater treatment include primary, secondary, and tertiary treatment using mechanical, chemical, and biological processes to remove solids, organic matter, and nutrients from wastewater [2÷4].

Wastewater treatment equipment was developed to reduce the negative/adverse effects of discharged effluents on aquatic ecosystems. Several wastewater treatment techniques have various efficiencies particularities and immediate consequences on the aquatic system. Sewage treatment plants generate high energy consumption and require large operating surfaces [5÷7]. The wastewater treatment methods with activated sludge are the most often used, but most of the time they are not sufficient to remove the forms of nitrogen and phosphorus and therefore post-treatment steps are necessary to remove nitrogen and phosphorus from the effluent. Since the effluents contain small amounts of organic compounds, in the post-treatment stage it is necessary to add an additional source of carbon to remove nitrogen and phosphorus from the effluent [8].

The process flow in wastewater treatment begins with preliminary treatment, the process in which grids and fine screens are used to remove large residues. The primary treatment (clarifier tanks) loads the influent into the tank, the solids (organics/sludge) settled on the bottom and are pumped to a sludge processing area. The secondary treatment known as biological treatment is designed to substantially degrade the biological content of the waste through aerobic biological processes (usually activated sludge process). Biological treatment with activated sludge is carried out in open basins (also known as aerotanks or bioreactors) equipped with oxygen generators and mixers to prevent the sedimentation of particles, creating a favourable environment for bacteria and aerobic microorganisms. Secondary activated sludge treatment process could include anaerobic, anoxic, and aerobic zones in order to reduce nitrogen and phosphorus concentration in the water. The wastewater with the activated sludge is discharged into final clarifier to ensure the separation of biological sludge from the clear treated water. Part of the settling biomass is removed from the system as the excess sludge, but most of it is returned to the aeration basin to maintain constant the bacterial population.

After secondary treatment, for wastewater reuse and disposal in sensible places, it is necessary an additional stage known as tertiary or advanced treatment. Technologies developed as wastewater tertiary treatment, usually involves filtration followed by additional disinfecting treatment (chlorine treatment, ultraviolet radiation, ozone treatment), and oxygen saturation.

There are many studies that showed the presence of a wide range of contaminants of emerging concerns in wastewater even after the treatment process with activated sludge. Such contaminants include pesticides, polycyclic aromatic hydrocarbons, and pharmaceutical and personal care products [9, 10].

A newer treatment technology available is the Membrane Biologic Reactor (MBR) which represents a complex, compact wastewater treatment developed to increase efficiency and have better results on discharged water quality. A Membrane Bioreactor is a process that combines the advantages of conventional activated sludge treatment with micro/ultra-membrane filtration.

Significant improvements offered by MBRs over the conventional activated sludge process are: superior effluent quality, higher biodegradation rates, smaller footprint, less sludge production and reuse possibilities. To evaluate the performance of WWTP, it is necessary to assess the physical-chemical parameters of the influent and effluent of the treatment plant [11, 12].

This paper focused on one WWTP located in the south-east of Romania, during its modernization process, which collects wastewater from different sources through the influent, benefits from a complex treatment process adapted to the degree of loading and discharging the effluent to a natural emissary (surface water). The evolution of the physical-chemical parameters of the inlet, and outlet discharge regarding pH, chemical oxygen demand (COD), biochemical oxygen demand (BOD_5), total suspended solids (TSS), volatile suspended solids (VSS), total nitrogen (TN), ammonia nitrogen (N-

NH_4^+), nitrates ($N\text{-}NO_3^-$), total phosphorus (TP) was monitored. In addition, the biodegradability index, a useful indicator to evaluate organic matter, was estimated.

MATERIALS AND METHODS

The wastewater samples were collected from a municipal WWTP, which was expanded and modernized in the period 2018÷2023 to ensure the treatment of the entire flow of wastewater (12 cubic meters per second), restoration of the ecosystem downstream of WWTP in the receiving rivers of the purified effluent, improving the quality of the groundwater in the area and reducing the pollution of the Danube and, implicitly, the Black Sea.

Sampling

The samples were collected from specific areas of the station, respectively station influent, secondary effluent (after the biological treatment stage) and final effluent (discharged into surface water). The samples were composite and collected at intervals of 24 hours for four weeks, between October and November 2023.

Methodology for measuring the parameters

COD was determined according to the standard EN ISO 6060:1989 [13].

BOD_5 was determined according to the European method standard EN ISO 5815-1:2020 [14]. A specific volume of sample was diluted with seeded dilution water and was stored in the dark at 20°C for 5 days. Oxygen concentrations, before and after five days of incubation, were measured in all sample dilutions using electrochemical method described by the standard EN ISO 5814:2012 [15]. BOD_5 was calculated for each sample dilution based on the difference between initial and final dissolved oxygen concentrations and includes a correction factor for oxygen depletion due to the presence of seed. The ratio of oxygen consumed over 5 days to the sample volume was also used to calculate BOD_5. The final BOD_5 value represents the average of the individual BOD_5 results for the sample dilutions.

For the water samples with biochemical oxygen demand lower than 6 mgO_2/L, BOD_5 was determined according to the standard EN ISO 5815-2:2022 [16]. The water sample was brought to 20°C and was aerated. After aeration, the sample was left to rest for 15 minutes and then it was stored in the dark at 20°C for 5 days, in completely filled and hermetically sealed vials. The BOD_5 value represents the difference between initial and final dissolved oxygen concentrations.

TSS was determined according to the SR EN ISO 872:2005 method [17]. For determination of VSS was applied standard STAS 9187-84 [18]. TN was performed in accordance with standard method SR EN ISO 20236:2021 [19], while for TP was applied method SR EN ISO 6878:2005 [20]. $N\text{-}NO_3^-$ were determined according to the SR EN ISO 7890-3:2000 method [22].

RESULTS AND DISCUSSION

COD results

During the 4 weeks of monitoring, the average values of COD for the influent samples are maintained within the specific limit values for an urban wastewater treatment plant, the average of the results obtained being 302 mgO_2/L. The average values obtained fall within the limits imposed by the national legislation NTPA 002 [23], the maximum allowed value being 500 mgO_2/L. Regarding the effluent samples, the average COD values being in the range of 24.70÷40.95 mgO_2/L for the secondary effluent and 24.57÷39.50 mgO_2/L for the total effluent (the value laid down in the national regulation NTPA 001 [24].

The influent and the effluent COD values are shown in Figure 1. The COD values recorded during the 4 weeks of monitoring, were within the allowed limits for both the influent and the effluent of WWTP, the lowest values being obtained in the second week.

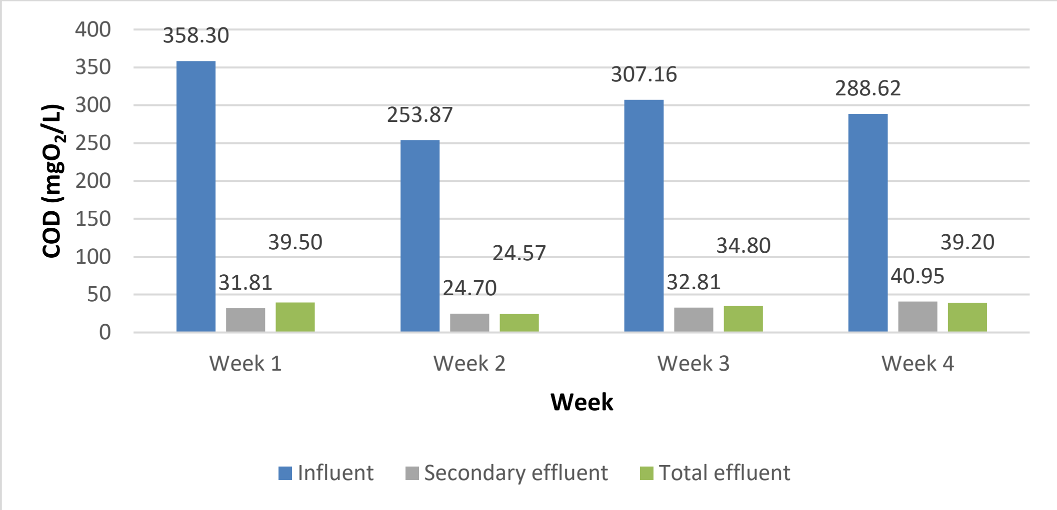

Fig. 1. Average values for chemical oxygen demand in mg O_2/L

BOD results

During the 4 weeks of monitoring, the average values of the biochemical oxygen demand (BOD_5) for the influent samples are maintained within the specific limit values for an urban wastewater treatment plant, the average of the results obtained being 59 mgO_2/L. The average values obtained fall within the limits imposed by the national legislation NTPA 002 [23], the maximum allowed value being 300 mgO_2/L. Regarding the effluent samples, the average BOD_5 values being in the range of 2.89÷6.57 mgO_2/L for the secondary effluent and 3.91÷6.28 mgO_2/L for the total effluent (the value laid down in the national regulation NTPA 001 [24].

The influent and the effluent BOD_5 values are shown in Figure 2. The BOD_5 values recorded during the 4 weeks of monitoring, were within the allowed limits for both the influent and the effluent of WWTP, the lowest values being obtained in the second week.

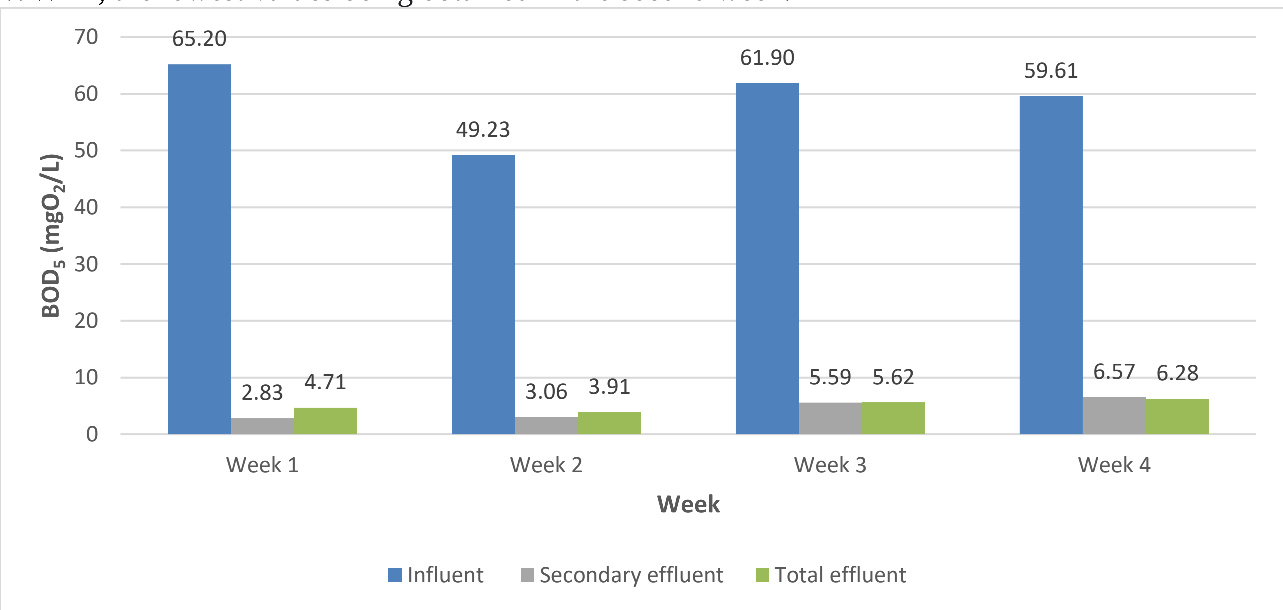

Fig. 2. Average values for biochemical oxygen demand in mg O_2/L

Biodegradability index (BOD_5/COD)

Typical values for the BOD_5/COD ratios for untreated municipal wastewater are in the approximate range of 0.3 to 0.8, while for wastewater samples with high content of hard biodegradable compounds, the index values are generally lower than 0.30. BOD_5/COD ratios decrease to 0.11÷0.31 for the treated sewage. If the ratio is equal to or greater than 0.5 the wastewater is considered to be easily

treatable by biological treatment. If the ratio is below 0.3, the wastewater may have some toxic components or acclimated microorganisms may be required for degradation [25].
The average values of the biodegradation index (Figure 3) for the influent samples are below 0.4, which is specified for the influent BOD_5/COD ratio according to the NTPA 002 regulation [23]. For the effluent samples, the average values recorded are lower than 0.20 (0.09÷0.16) indicating a good treatability of the influent. Also, the low COD and BOD_5 values obtained for all analysed effluent samples are within the tolerance limits of discharged wastewater into a natural emissary [24].

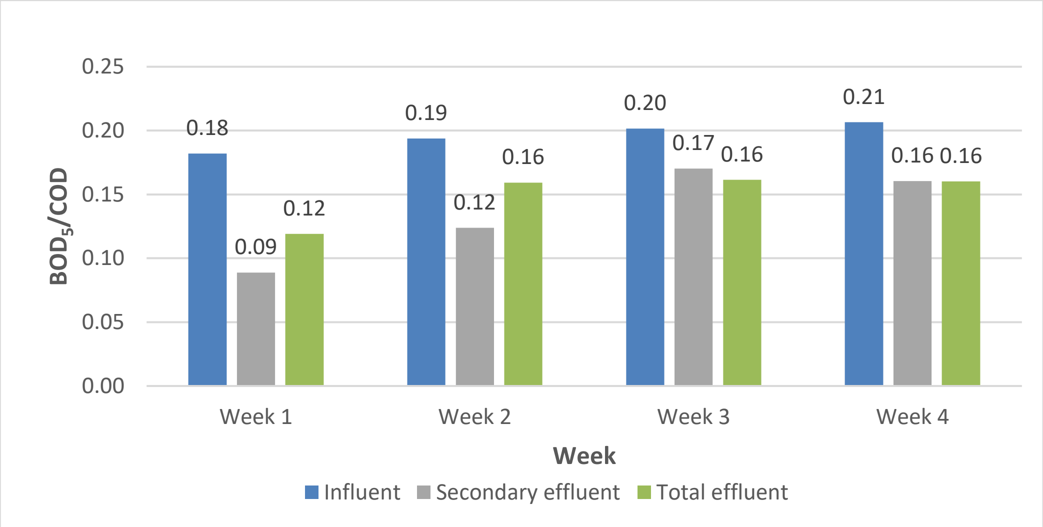

Fig. 3. Biodegradability index

Nitrogen and phosphorus compounds
The presence of ammonium, phosphorus and organic matter in purified wastewater has a contribution of 95% in the process of eutrophication of their emissions [26].
The main sources of phosphorus pollution of wastewater were the use of phosphate in fertilizers and in phosphate laundry detergent. The phosphorus concentration recorded over time, in the influent of treatment plants in the USA was over 11 mg/L, which determined, from 1994, the prohibition of the use of cotton wool in laundry detergent, the measure that had results, phosphorus concentrations in the effluents of the sewage treatment plants dropping to 5 mg/L [27].
In order to prevent the eutrophication of surface waters, it is necessary to simultaneously remove nitrogen and phosphorus from the secondary effluent of the treatment plants. The concentrations of total nitrogen and total phosphorus in surface waters (rivers, lakes) that can lead to eutrophication are between 0.5 mg/L and 1.2 mg/L and, respectively, 0.03 mg/L and 0.1 mg/L [28].
The main processes for the simultaneous removal of nitrogen and phosphorus are the use of the improved denitrification filter for phosphorus removal, pyrite-based autotrophic denitrification and the biological method with microalgae [29].
Microalgae biofilms are used as post-treatment for wastewater treatment plants, resulting in the ability to remove phosphorus and nitrogen in the ratio in which they are found in wastewater [30].
The WWTP evaluated in the present study applies a post-treatment step with activated sludge and the addition of a carbon source to remove phosphorus and nitrogen.

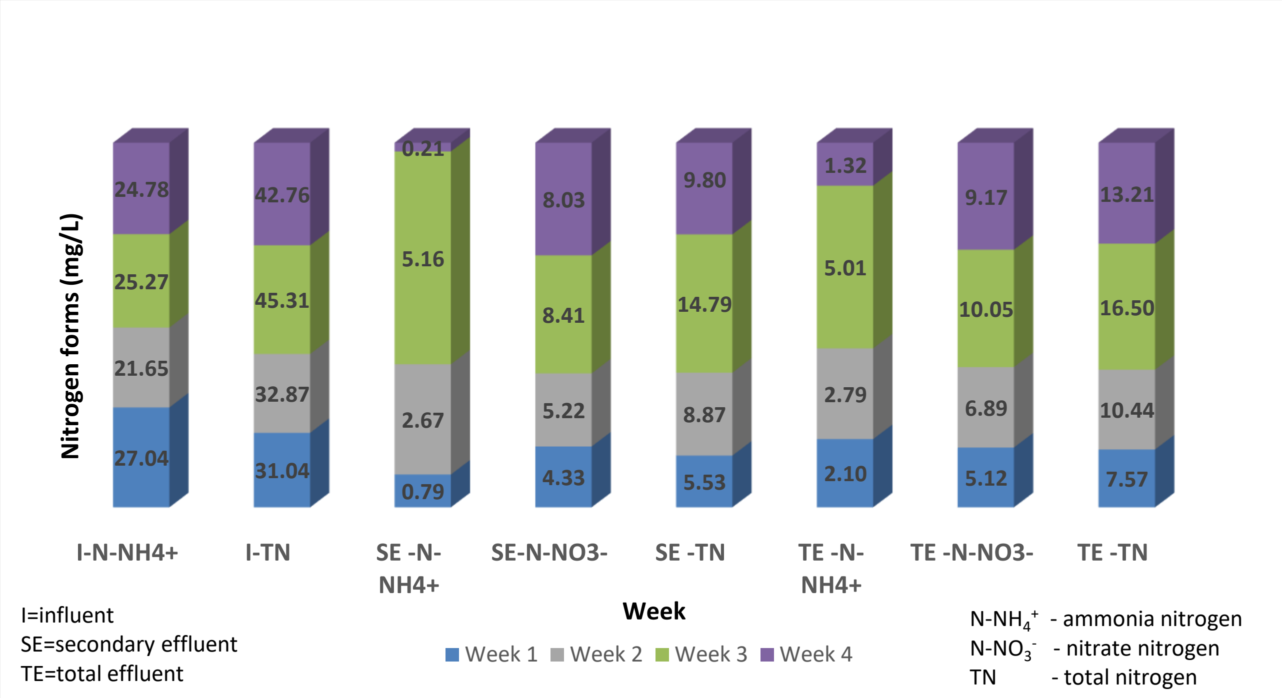

Fig. 4. Average values of nitrogen compounds

From Figure 4 it can be seen that the average weekly total nitrogen concentrations in the sewage treatment plant influent were between 31.04 and 45.3 mg/L, while for the secondary effluent the total nitrogen concentrations were between 5.5 and 14.8 mg/L. For the total effluent, the total nitrogen concentrations were between 7.57 and 16.5 mg/L. The total nitrogen has no limit imposed by the national legislation NTPA 001 and NTPA 002 [23, 24].

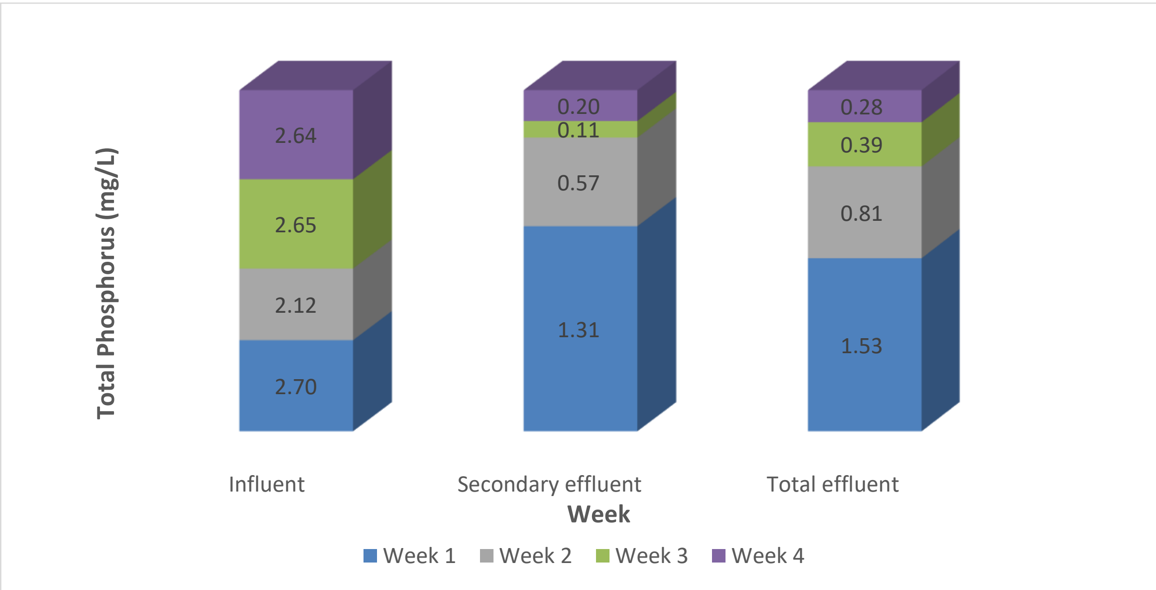

Fig. 5. Total Phosphorus, average values

Analyzing the graphs in Figure 5, it can be seen that the average weekly concentrations of total phosphorus in the influent of the treatment plant were between 2.1 and 2.7 mg/L. The average values obtained fall within the limits imposed by the national legislation NTPA 002 [23], the maximum allowed value being 5 mg/L. For the secondary effluent, phosphorus concentrations registered a significant decrease compared to the influent, being between 0.11 and 1.31 mg/L. It is observed that with the decrease of the organic load in the treated wastewater, the concentration of total phosphorus increases, the values being between 0.28 and 1.53 mg/L (the value laid down in the national regulation NTPA 001 [24].

TSS and VSS

As can be seen from Figure 6, there are no major variations in the two analyzed parameters VSS (volatile suspended solids) and TSS (total suspended solids), the average values being 146.5 mg/L for influent VSS and 167.5 mg/L for influent TSS. The average values obtained fall within the limits imposed by the national legislation NTPA 002 [23], the maximum allowed value being 350 mg/L for TSS, while VSS has no limit imposed by the national legislation. The average value of TSS is 4.53 mg/L for secondary effluent and 4.06 mg/L for total effluent (the value laid down in the national regulation NTPA 001 [24]. The average value of VSS is 3.06 mg/L for secondary effluent and 2.59 mg/L for total effluent.

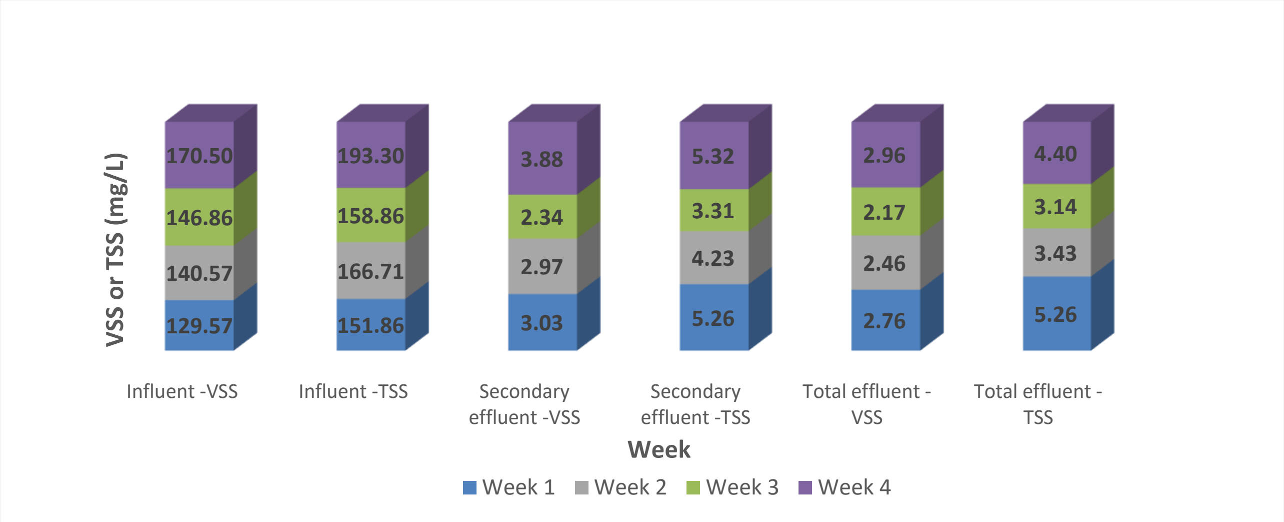

Fig. 6. Content of suspended solids (VSS, TSS), average values

Removal efficiency

The removal efficiency of the major pollutants of wastewater was calculated using equation (1):

$$E\% = (1 - c\_eff/c\_inf)x100 \quad (1)$$

where: E% - removal efficiency, in percentage; C_{eff} – total effluent pollutants concentrations, in mg/L; C_{inf} – influent pollutants concentrations, in mg/L.

Table 1. Removal efficiency of major pollutants of wastewater

Week	Removal efficiency COD (%)	Removal efficiency BOD_5 (%)	Removal efficiency TSS (%)	Removal efficiency VSS (%)	Removal efficiency TN (%)	Removal efficiency TP (%)	Removal efficiency N-NH_4^+ (%)
Week 1	88.98	92.78	96.54	97.87	70.62	43.44	92.25
Week 2	90.32	92.05	97.94	98.25	68.23	61.87	87.11
Week 3	88.67	90.92	98.02	98.52	63.59	85.28	80.19
Week 4	86.42	89.46	97.72	98.26	69.11	89.29	94.67

As we can see in Table 1, the average efficiency values remain constant for COD (88%), BOD_5 (91.3%), TSS (97.5%), VSS (98.2%), total nitrogen (69.1%) and ammonia nitrogen (88.5%). For total phosphorus, a considerable improvement in the removal efficiency was registered, from an average value of 43.44% in the first week, to an average value of 89.29% in the fourth week.

CONCLUSIONS

Wastewater quality monitoring was carried out after the period of WWTP expansion and modernization (performed in the period 2018-2023), the measured parameters (organic load, nutrients, suspended matter and surfactants) were selected according to their representativeness in the evaluation of the WWTP efficiency and the obtained results highlighted:

- high removal efficiencies for the parameters chemical oxygen demand, biochemical oxygen demand, total suspended solids, volatile suspended solids and ammoniacal nitrogen;
- the biodegradability capacity of the wastewater, expressed according to the BOD_5/COD ratio showed an average value of 0.2 in the influent station, indicating the hard-to-degradate character of some compounds/substances in the composition of the wastewater;
- falling within the normative limits for discharging the WWTP's effluent into the natural emissary, according to the national regulations in force.

To sum up, most of the physical-chemical parameters exhibited consistently high removal efficiency values, except for total phosphorus. However, after the station's modernization and expansion, the efficiency in removing total phosphorus increased from 43.44% to 89.29%.

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