

ASSESSMENT IN TREATMENT EFFICIENCY OF A SMALL-SCALE MUNICIPAL WASTEWATER TREATMENT PLANT WITH ACTIVATED SLUDGE

MARIJANA BUBALO^{1,2}, IVANA ŠUMELJ², KATARINA HERCEG³, NEDILJKA VUKOJEVIĆ MEDVIDOVIĆ ⁴

¹Faculty of Agriculture and Food Technology, University of Mostar, Biskupa Čule bb, 88000 Mostar, Bosnia and Herzegovina; e-mail: marijana.bubalo@aptf.sum.ba

²Public Enterprise “Parkovi”, Nikole Šopa 8, 88320 Ljubuški, Bosnia and Herzegovina; e-mail: marijanabubalo.pbf@gmail.com, ivanasumelj19@gmail.com

³Public Health and Environ. Eng., University of Mostar, Zrinskog Frankopana 34, 88 000 Mostar, Bosnia and Herzegovina; e-mail: katarina.herceg@fzs.sum.ba

⁴Faculty of Chemistry and Technology in Split, University of Split, Ruđer Bosković 35, 21000 Split, Croatia; e-mail: nvukojev@ktf-split.hr

 Corresponding author

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Abstract

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In this paper, the treatment efficiency of a small-scale wastewater treatment plant (WWTP) with activated sludge was analysed in order to examine the impact of variations in the composition of incoming raw municipal wastewater. The characteristics of the wastewater were analysed with respect to COD, BOD₅ and TSS values and loading during the two years, 2018 and 2019. The mixed liquid suspended solid (MLSS), sludge volume index (SVI), food to microorganism ratio (F/M), sludge age and hydraulic retention time (HRT) were used for evaluation of the performance of WWTP. Removal percentage is in the order of TSS > BOD₅ > COD during 2018, while in 2019 is in the order BOD₅ > TSS > COD. However, better values of removal efficiency for COD, BOD and TSS are obtained in 2019, which is connected to lower oscillation values of MLSS and SVI index. Biodegradability ratio of raw and treated wastewater, plant reliability factor (RF) and equivalent number of inhabitant (ENI) were determined. In addition, the economic cost of small-scale wastewater treatment plant (WWTP) with activated sludge was evaluated and discussed.

Key words: physicochemical indicators, wastewater treatment plant, activated sludge, sludge volume index, plant reliability factor.

Introduction

The increase of the human population and industry development requires large quantity of water which leads to the generation of large amounts of wastewater. Discharges of untreated wastewater into natural water systems, agricultural lands or forest holdings cause undesirable changes in the environment which are dangerous to human health and aquatic ecosystems. Depending on the size of the receiving capacity of individual receivers, possible disturbances of the natural biological balance of water systems are visible only after a certain time. Wastewater collection and treatment are particularly important in karst areas where, due to high soil permeability, pollutants easily and quickly enter groundwater. The presence of underground streams and caverns is frequent in the karst relief. Permanent and intermittent large karst springs are common (Herak, 1986).

Municipal wastewater treatment plants collect and treat not only wastewater from household but also from industrial complexes. However, some industrial discharges contain a large amount of non-biodegradable organic matter, which cannot be treated properly in a conventional biological WWTP (Choi et al., 2017). In addition, some sewage plants also receive septage or

septic tank solids from household on-site wastewater treatment systems, which additionally complicate treatment process.

The activated sludge process was first applied in England in 1914 for the treatment of household wastewater, and the starting point is generally attributed to the work of Arden and Lockett (Orhon, 2015). Soluble substances of simple chemical structure, such as carbohydrates, fats, proteins, alcohols and lower fatty acids, are components of household wastewater, food and fermentation industries, and can be completely decomposed by activated sludge. Degradation of constituents of complex chemical structures requires long-term adaptation of activated sludge, whereby microorganisms that have biochemical activity for the decomposition of complex chemical constituents are maintained in the activated sludge. Microorganisms are dispersed in wastewater in the form of flakes or flocs (D'Antoni et al., 2017). The substrate represents a biodegradable organic substance in wastewater and is usually measured as 5-day biochemical oxygen demand (BOD₅) (Richard, 2003). A constant contact between the microbial mass (flakes), substrate as support for the growth of microorganism and oxygen is achieved by intensive mixing. At the end of process, the microbial mass-bioactive sludge is separated from the treated wastewater by gravity deposition (Moussaoui et al., 2019).



Fig. 1. Location and current state of the WWTP Ljubuški.

Wastewater treatment is a key link in the services provided by the water supply and sewerage sector to society (van Loosdrecht et al., 2016). As wastewater should be properly treated and discharged into receivers, it is necessary to analyse the physical, chemical and biological indicators of water quality at the inlet and outlet of the treatment plant, and to obtain treatment efficiency (Briški, 2016; Višekruna et al., 2011).

Although the activated sludge process has a long history of application (Hreiz et al., 2015), analysis and improvement of treatment efficiency are still under the investigation of many authors, especially with regards to analyses of the influent quality variation on the efficiency of wastewater treatment plant. Kumar et al. (2010) investigated overall efficiency expressed through total dissolved solids (TDS), chemical oxygen demand (COD), total suspended solids (TSS) and five-day biochemical oxygen demand (BOD_5) of the Mailsandra and Nagasandra sewage treatment plant for a period of seven days. They conclude that fresh sludge with higher microorganism population should be recycled and the aerators must be operated continuously to achieve better performance. Vitez et al. (2012) investigated treatment efficiency of small wastewater treatment plants of 500 and 2000 PE (population equivalent) near the Moravian Karst during one year. They found out that very low reduction of pollution is due to hydraulic overloading and a very low metabolic load of wastewater enters the wastewater treatment plant. Hegazy et al. (2016) had analysed the removal efficiency of Shoubra Al Khaima (Balqus) wastewater treatment plant for a period of six months. They found out that treatment plants operate with removal efficiency higher than 90% for BOD_5 , COD, TSS and oil/grease. Dahamsheh and Wedyan (2017) evaluated the performance of Al-Hussein bin Talal University (AHU) wastewater treatment plant monthly for three years, expressed through efficient removal of BOD_5 , COD and TSS. In addition, they evaluated the correlation between the BOD_5 and COD which confirm high biodegradability index.

It is evident from the above-mentioned papers that performance assessment is important to analyse the influent quality variation on the efficiency of wastewater treatment plants. Thus, in this paper, a comprehensive analysis of treatment efficiency of a small scale wastewater treatment plant (WWTP) with activated sludge in Ljubuški was conducted. The analysis is based on TSS, COD and BOD_5 in influent and effluent, sludge volume index

(SVI) and mixed liquid suspended solids (MLSS) values in aeration basin, as well as design parameters such as food to micro-organism (F/M), sludge age and hydraulic retention time (HRT), measured for two years in 2018 and 2019. Biodegradability ratio of raw and treated wastewater, plant reliability factor (RF) and equivalent number of inhabitant (ENI) or population equivalent (PE) were evaluated for each year. In addition, the economic cost of small-scale wastewater treatment plant was evaluated and discussed. Such comprehensive study will be very useful in achieving optimal process control of small WWTP in Ljubuški as well as for comparison of the treatment efficiency with other similar wastewater treatment plants.

Material and methods

Description of WWTP

The wastewater treatment plant with activated sludge is located in the municipality of Ljubuški, at the southern part of Bosnia and Herzegovina, in the west of Herzegovina along the border of the Republic of Croatia. The town of Ljubuški is located on the left bank of the Trebižat, a river with numerous waterfalls, among which the most famous ones are Kravica and Koćuša. In the municipality of Ljubuški, there are currently 2,556 registered connections on the public sewerage system. Maintenance and supervision of the sewerage system as well as wastewater treatment device are the responsibility of Public Enterprise 'PARKOVI' Ljubuški. The sewerage system is a mixed type, mainly covering the narrower part of the city. The rural part of the municipality of Ljubuški does not have a sewerage system. All of the wastewater comes by gravity through the collector pipe to the WWTP Ljubuški which is located in Matinevac (southwest of the city center), about 350 m away from the confluence in the recipient—the Trebižat river. Location and current state of the WWTP Ljubuški are given in Figure 1.

The wastewater treatment plant in Ljubuški is intended for the secondary treatment of a capacity of 6,000 PE (or equivalent number of inhabitants, ENI) (Štrbenac, 2013). The mechanical pre-treatment line consists of a coarse grid (40 mm), a fine grid (12 mm), a fine sieve with a press (3 mm) and an aerated sand trap. The mechanical pre-treatment is followed by biological treatment of wastewater in a bio-aeration basin with a vol-

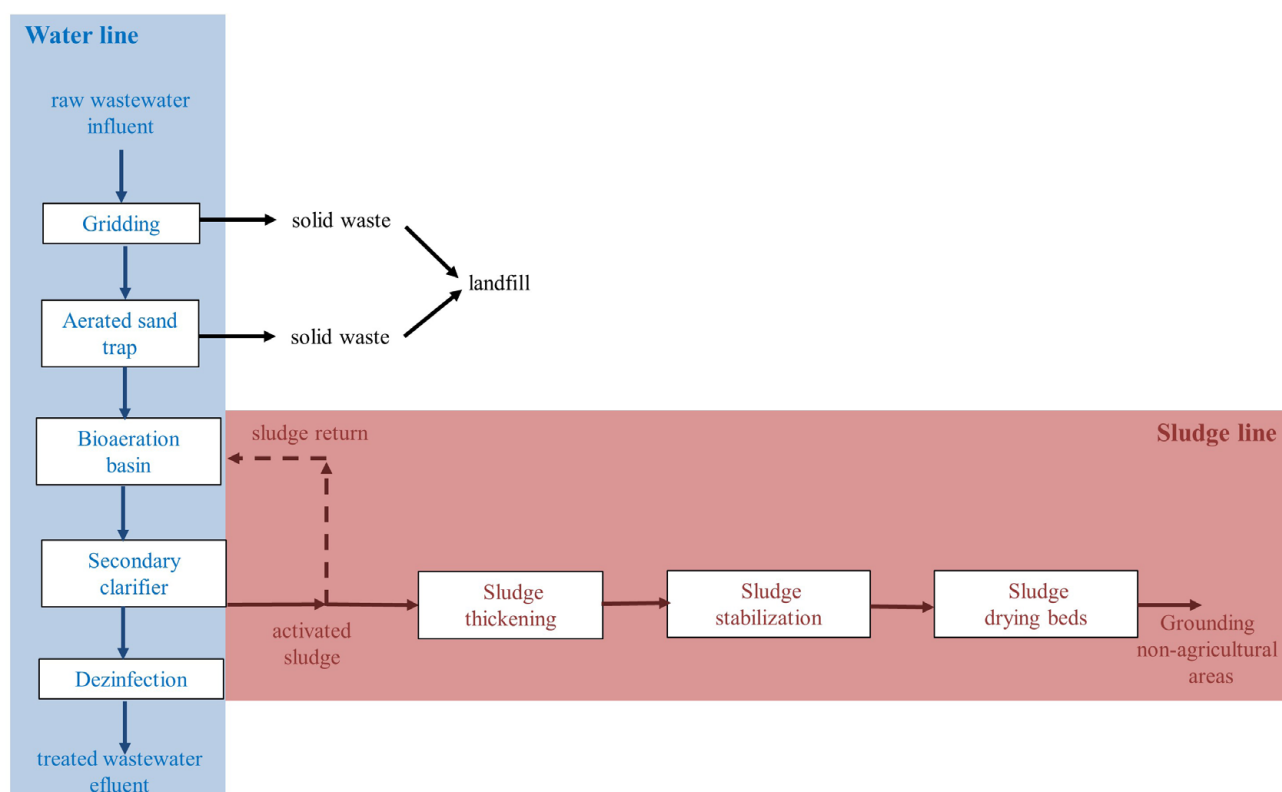


Fig. 2. Scheme of the process performed in the WWTP Ljubuški.

Table 1. Emission limit values for the discharge of treated wastewater from urban/municipal wastewater treatment plants into natural recipient (Regulation FBiH 26/20).

Parameter	Emission limit value or the permissible concentration in treated sewage	Minimum percentage of load reduction
Biochemical oxygen demand (BOD ₅ at 20°C)	25 mg O ₂ /L	70-90%
Chemical oxygen demand (COD)	125 mg O ₂ /L	75%
Total suspended solids (TSS)	35 mg/L	90%

ume of 1,156 m³, where aeration takes place via immersed bottom blowers. From the bio-aeration basin, the outlet stream is taken to a secondary clarifier in which the activated sludge is deposited at the bottom, and the purified and clarified water is discharged into the receiver. After the secondary clarifier, and before discharging into the receiver (Trebižat river), the purified water can be preceded for disinfection if necessary. Part of the activated sludge from the secondary clarifier is returned to the bio-aeration basin, while the rest of the activated sludge is processed into sludge thickener and discharged into the sludge drying fields, after which it is mixed with ground and used for grounding non-agricultural areas. Figure 2 shows a scheme of the process performed in the WWTP Ljubuški.

The recipient is the Trebižat river, according to the Law on Waters of the Federation of Bosnia and Herzegovina (Official Gazette of FBiH 70/06, Art. 5) belongs to the category I of watercourses according to importance. The quality of the discharged effluent water from the treatment plant should have met the cri-

teria for discharge into surface water bodies (Regulation FBiH 26/20) as well as requirement for achieving the minimum percentage reductions (Table 1).

Sampling and analytical procedure

Analysis of raw and treated sewage

Raw sewage (influent) was sampled on the channel of the mechanical pretreatment line behind the fine grid. The treated sewage (effluent) was sampled at the outlet shaft of the device next to the outlet flow meter, before discharging into the natural recipient, the Trebižat river. Sampling was performed with an automatic sampler HACH-type SIGMA 900. During 24 hours, samples were periodically taken in 24 separate bottles located in a cooled sampler tank. To obtain a representative sample, a composite 24-hour sample was made and analysed in the laboratory. Sampling was done 18 times during 2018 and 19 times during

2019, and the COD, BOD₅ and TSS were analysed in each sample, previously homogenised.

The chemical oxygen demand (COD) was determined spectrophotometrically by the bichromate method on a HACH DR 3900 spectrophotometer using LCK 514 100-2,000 mg O₂/L inlet reaction test cuvettes and LCK 314 15-150 mg O₂/L outlet reaction test cuvettes. The five-day biochemical oxygen demand (BOD₅) was determined spectrophotometrically on a HACH-type DR 3900 spectrophotometer using LCK 555 4-1,650 mg/L BOD₅ cuvette test reaction and incubation in a thermostat for five days at a temperature of 20 °C. Total suspended solids were determined by filtering a known volume of wastewater through dry and pre-weighed 0.45 µm pore size filter paper, using a vacuum pump. The filter paper with the precipitate is then dried in an oven at 105 °C for 75 minutes to constant weight. The calculated difference in the mass of the filter paper before and after filtration and drying, divided by the volume of the filtered wastewater sample, represents the amount of total suspended solids (TSS) expressed in mg/L.

Analysis of activated sludge settling ability

Activated sludge settling ability was measured through the determination of mixed liquor suspended solids (MLSS) and sludge volume index (SVI).

Mixed liquor suspended solids (MLSS in g/L) represent the total concentration of mixed liquor suspended (non-soluble) solids in the aeration basin of an activated sludge system. MLSS was determined by filtering a known volume of the mixed liquor sample from an aerated basin, dried to a constant weight at a temperature between 103 and 105 °C, and weighed. The optimal range of MLSS for conventional activated sludge plants is 2 to 4 g/L (Dippold, Gerold, 2013).

Sludge volume index (SVI) is an indicator of settleability and ability to compact the sludge from the aeration basin. A 1,000 mL of sample of mixed liquor suspended solid was collected from the aeration basin and allowed to settle in a jar for 30 minutes. According to Kumar et al. (2010), the SVI was calculated by dividing the settleability by the MLSS concentration. The typical range of SVI is 50-150 mL/g (Szelag et al., 2018).

Calculation of the main parameters of the process

The food/microorganism ratio (or F/M) is a measurement of the food entering the activated sludge process and the microorganisms in the aeration basin (Gerardi, 2002). It is calculated from the influent BOD₅ and the mixed liquor suspended solids MLSS. Common values of F/M for a conventional activated sludge plant are in the range of 0.15–0.5 kg BOD₅/kg MLSS per day.

Sludge age is a parameter which helps to maintain the desired amount of solids in the aeration basin. It is defined as the average time in days the suspended solids remain in the system. It is calculated from the solids entering the reactor (expressed as TSS) and mixed liquor suspended solids (MLSS). The common range for conventional activated sludge plant is between 3 and 15 days.

Hydraulic retention time (or HRT) represents the amount of time in hours for wastewater to pass through the aeration basin. It is calculated by dividing the volume of aeration basin and the flowrate.

Calculation of removal efficiency, plant reliability and actual efficiency

The removal efficiency was calculated according to Equation (1) (Vitez et al., 2012):

$$\text{Removal efficiency (in \%)} = \frac{[\text{influent values} - \text{effluent values}]}{\text{influent values}} \cdot 100 \quad (1).$$

The initial values correspond to the parameters of the influent, while the final values correspond to the parameters obtained in the effluent.

According to Garbowski et al. (2018), actual efficiency of treatment plant operation can be evaluated by the calculation of actual values of equivalent number of inhabitants (ENI) (or population equivalents), according to Equation (2):

$$\text{ENI} = \frac{\text{TLR}_{\text{BOD}_5}}{\text{ULR}_{\text{BOD}_5}} \quad (2),$$

where ENI - the equivalent number of inhabitants; TLR_{BOD₅} - the total BOD₅ loading rate (g/day); ULR_{BOD₅} - the unitary BOD₅ loading rate (60 g/capita day).

Plant reliability factor (RF) as an indicator of proper operation of the WWTP in relation to individual indicators of pollutants and is calculated according to Equation (3):

$$\text{RF} = \frac{\bar{x}}{x_{\text{per}}} \quad (3),$$

where RF - the plant reliability factor; $\bar{x}$ - the average concentration of a pollutant indicator in the treated sewage (mg/L); x_{per} - the permissible concentration of a pollutant indicator in the treated sewage (mg/L).

Results and discussion

Analysis of COD, BOD₅ and TSS in influent and effluent

The values of COD, BOD₅ and TSS monitored at the WWTP during 2018 and 2019 in influent and effluent are graphically compared in Figures 3–5. In addition, COD, BOD₅ and TSS loadings were also calculated and compared in Figs 3–5. COD, BOD₅ and TSS loadings were calculated by multiplying the concentration values of each parameter with daily effluent volume (Gerardi, 2002).

It is evident from Figure 3 that COD values and COD load in the influent are varied in dependence of sampling time. However, the COD values in the influent were more pronounced in 2019 compared to 2018. Maximum values are observed at the end of April and during October 2019, and are associated with illegal discharge from local facilities (such as food processing, restaurants, car service, etc.) into the sewage system without prior treatment. Calculated COD loading is mostly in line with increased COD values. Small deviations are observed in February 2018, and at the end of April and October 2019, which indicate

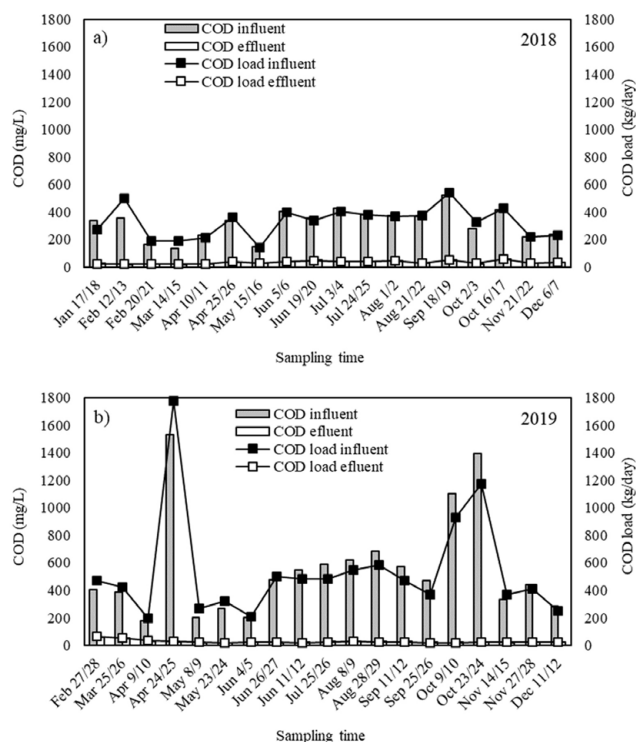


Fig. 3. COD values and COD load in the influent and effluent at the WWTP during years: a) 2018 and b) 2019.

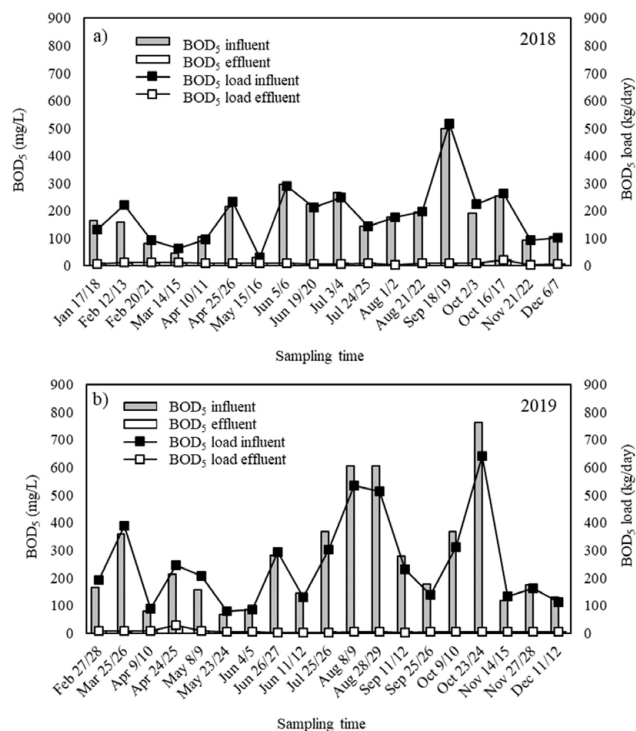


Fig. 4. BOD₅ values and BOD₅ load in the influent and effluent at the WWTP during years: a) 2018 and b) 2019.

Table 2. Minimum, maximum, average values and standard deviation of the main parameters at the WWTP Ljubuški measured during 2018 and 2019.

Year	2018				2019			
	Min	Max	Average	SD	Min	Max	Average	SD
Flowrate, m ³ /day	801.00	1398.00	1044.83	150.14	787.00	1212.00	987.47	158.97
COD _{influent} , mg/L	138.00	522.00	316.56	106.24	177.00	1534.00	563.21	384.06
COD _{effluent} , mg/L	16.00	57.50	34.38	12.04	16.30	58.40	27.66	10.58
BOD _{5influent} , mg/L	31.00	497.00	179.94	108.72	66.00	763.00	270.63	198.96
BOD _{5effluent} , mg/L	2.46	22.00	8.98	3.75	2.00	24.00	5.95	4.58
TSS _{influent} , mg/L	38.60	365.00	111.41	78.07	40.00	776.00	178.11	213.50
TSS _{effluent} , mg/L	1.20	12.00	5.19	2.91	1.60	12.00	4.78	2.53
MLSS, g/L	0.67	1.22	0.91	0.14	0.40	2.49	1.80	0.58
SVI, mL/g	52.08	823.53	283.81	200.95	44.58	482.14	216.09	122.86
F/M ratio, kg BOD ₅ /(kg day)	0.04	0.49	0.18	0.11	0.03	0.37	0.14	0.10
Sludge age, day	2.89	27.49	11.53	6.02	3.25	56.61	22.50	16.54
HRT, day	0.83	1.44	1.13	0.15	0.88	1.47	1.20	0.18

Notes: min - minimum values; max - maximum values; average - average values; SD - standard deviation of measured parameters.

that an increased in COD loading is due to the change in composition and quantity of wastewater coming to the WWTP. COD values in the effluent do not exceed the maximum permissible value of 125 mg/L set by the regulation (Table 2).

Similar behaviour is observed with BOD₅ values and BOD₅ load in the influent (Fig. 4), which shows variation in depend-

ence of sampling time. The BOD₅ values in the influent are slightly higher in 2019 compared to 2018. Maximum values are observed in September 2018, August 2019, and October 2019. BOD₅ loading is mostly following the variation in BOD₅ values, which indicates that increase in BOD₅ load is due to variation in composition of wastewater coming to the WWTP rather than

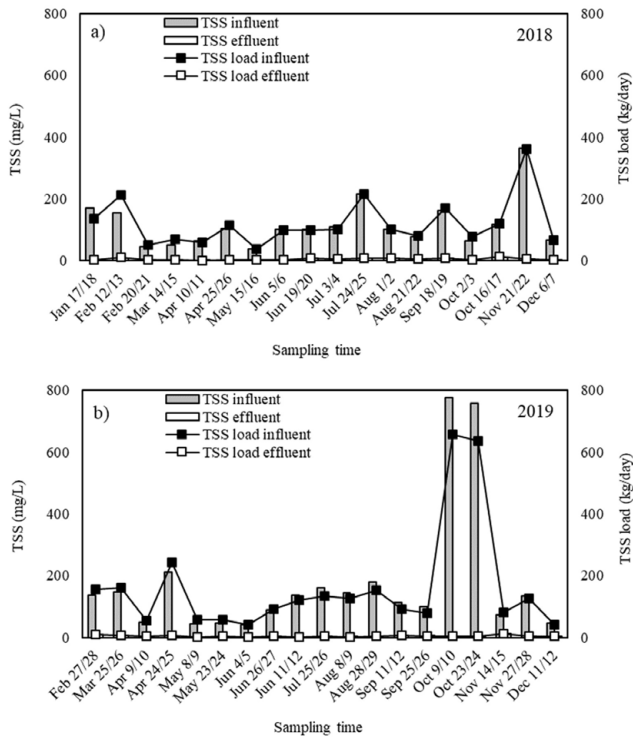


Fig. 5. TSS values and TSS load in the influent and effluent at the WWTP during years: a) 2018 and b) 2019.

variation in wastewater flow. Additionally, there was no exceeding of the maximum permissible value of BOD_5 of the effluent determined by the Regulation, which is 25 mg/L (Table 2).

The TSS values and loads are also oscillating (Fig. 5). The highest value of TSS of the influent was noted during October 2019 in the amount of 776 mg/L, and is also associated with illegal discharge of wastewater from local facilities into the sewage without prior treatment. However, the values of the TSS of the effluent did not exceed the maximum permissible concentration of 35 mg/L (Table 2). In comparison with wastewater loading coming from COD and TSS (Fig. 3, Fig. 5), it is evident that the loading of wastewater with dispersed matter is almost three times lower compared to load of wastewater with COD.

Analysis of MLSS and SVI in activated sludge

The performance of the WWTP can be monitored by the sludge volume index (SVI) and the mixed liquor suspended solids (MLSS) (Khan et al., 2020). The MLSS concentration in the aeration tank directly determines the solids loading rate to the final clarifier, which makes it a very important operating parameter (James et al., 2015). On the other hand, the sludge settling ability is considered as a critical step where filamentous bulking and biomass deflocculating are the most common problems, causing the reduction of the effluent quality (Mesquita et al., 2008). Figure 6 compares the results of the MLSS and SVI on WWTP Ljubuški in 2018 and 2019.

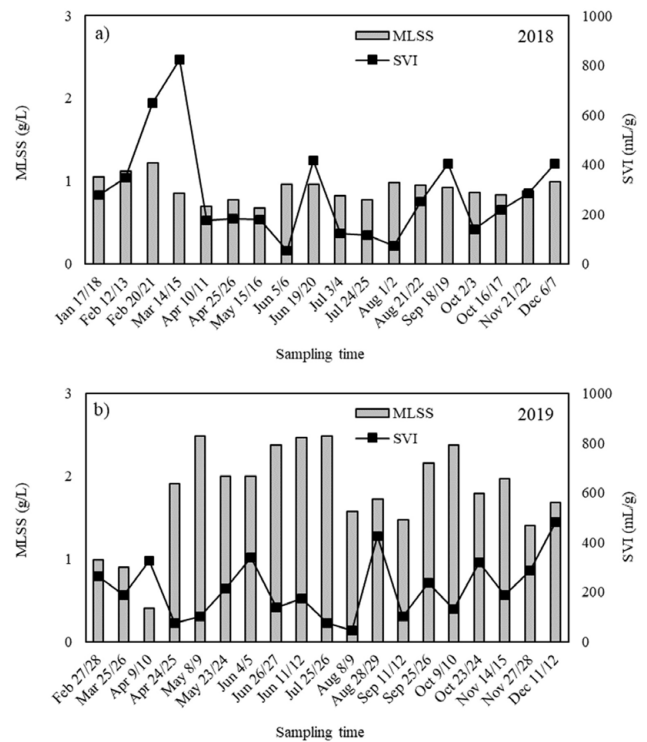


Fig. 6. MLSS and SVI at the WWTP during years: a) 2018 and b) 2019.

It is evident from Figure 6 that the values of the MLSS in 2018 had an oscillating range of 0.67–1.22 g/L (average value 0.91 g/L), while in 2019, this oscillating range was 0.40–2.49 g/L (average values 1.80 g/L). As the typical range of the MLSS is 2 to 4 g/L, lower average values of the MLSS are influencing on settleability and compact ability of the sludge, expressed as SVI. It is evident that SVI in 2018 had a wide oscillating range of 52.08–823.53 mL/g (average value 283.81 mL/g), while in 2019, these values were 44.58–482.14 mL/g (average values 216.09 mL/g). As the typical range of SVI is 50–150 mL/g, significantly higher values can relate to excessive increase of filamentous bacteria in the activated sludge, and thus, the problem of bulking during clarification may occur (Szelag et al., 2018). Higher values of SVI are usually an indication of young sludge condition, or the result of toxic influent loading or a clarifier solids washout event. Lower values of SVI influence rapid settling abilities, which are usually the result of pin floc, commonly caused by old, over-oxidised sludge. Based on oscillating values of the MLSS and SVI during 2018 and 2019 at the WWTP, it indicates that slightly better removal efficiency of COD, BOD and TSS was obtained during 2019 (Fig. 12).

Food to microorganism ratio and sludge age comparison

The food-to-microorganism ratio (F/M ratio) is an indication of the ratio between the amount of microorganisms to the amount of food. Thus, it will be very useful to analyse the variation of F/M ratio regarding the SVI index (which represents the sludge settleability).

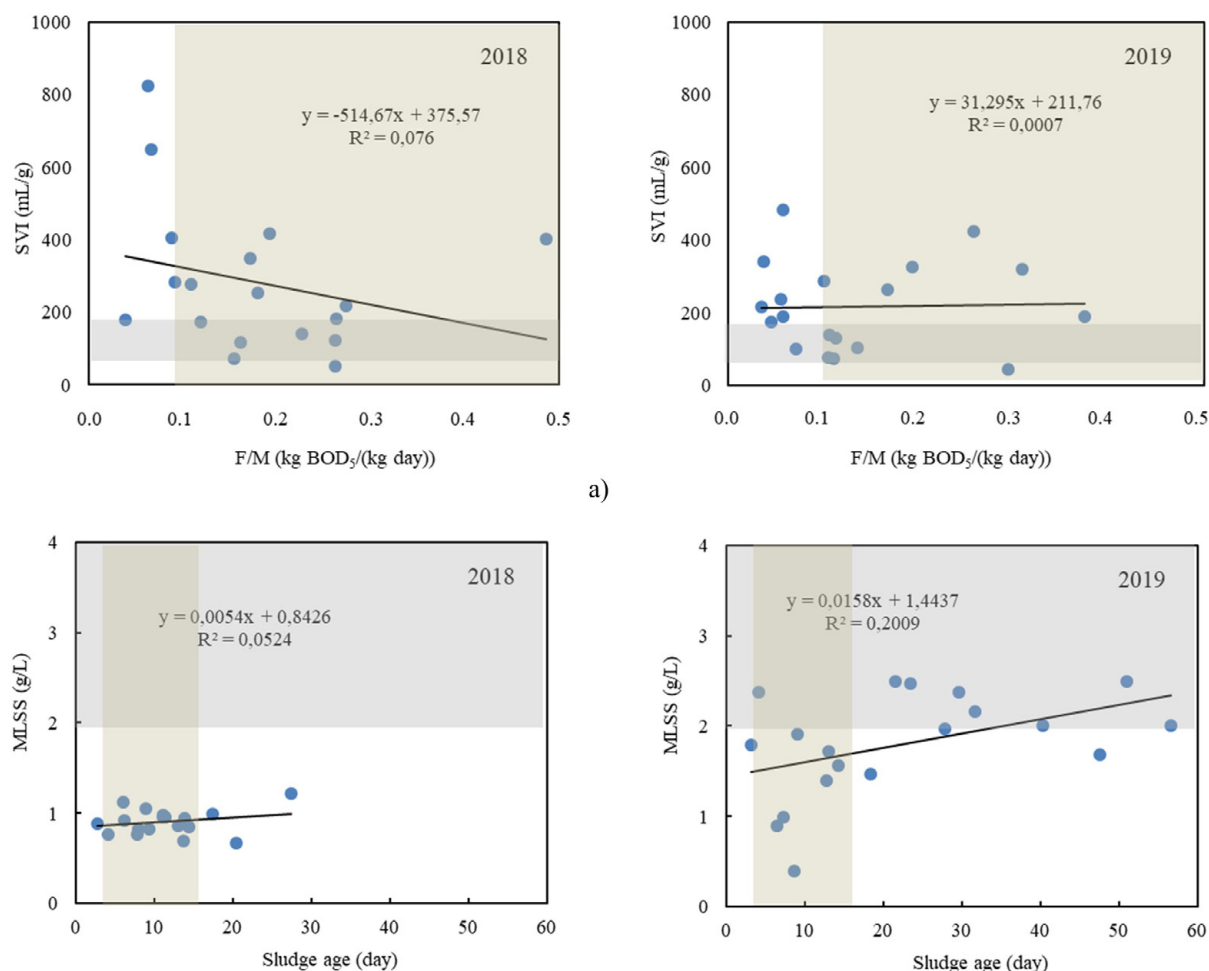


Fig. 7. a) Sludge volume index (SVI) vs. food to microorganism ratio (F/M ratio) during 2018 and 2019; b) mixed liquor suspended solid (MLSS) vs. sludge age. Note: two shaded areas represent the optimal SVI range of 50-150 mL/g, and the optimal range of F/M ratio of 0.1-0.5 kg BOD₅/(kg day). Note: two shaded areas represent the optimal of MLSS in the range of 2-4 g/L and the optimal range of sludge age in the range of 3-15 days.

Figure 7(a) represents the variation in values of the SVI in dependence of F/M ratio during 2018 and 2019. The two shaded areas represent the optimal SVI range of 50-150 mL/g and optimal F/M ratio range of 0.1-0.5 kg BOD₅/(kg day), respectively. It is evident that the correlation between F/M ratio and SVI is quite poor. Some points belong to a low F/M ratio which is an indication of higher amounts of microorganisms but with limited amounts of food. A very low F/M ratio will result in dispersed floc that will not settle well in the secondary clarifier. It is evident that only a small number of points belong to the intersection of both shaded areas. However, the values of SVI index during 2018 are quite dispersed compared to 2019 (R^2 is very low), which probably influenced slightly lower removal efficiency.

Sludge age is the most important parameter for sludge characterization as it gives indication of average residence time of the microorganisms in the activated sludge plant. The MLSS concentration in the aeration tank is controlled by the sludge age (James et al., 2015). Figure 7(b) compares

the MLSS in dependence of the sludge age. The two shaded areas represent the optimal MLSS in the range of 2-4 g/L and the optimal range of sludge age in the range of 3-15 days, respectively. The correlation between sludge age and the MLSS is quite poor, even it is evident that reducing the sludge age reduces the MLSS. Only a few points during 2019 belonged to both shaded areas, and points are more scattered compared to 2018. Sludge age during 2018 is varying in the range of 2.89-27.49 days (average value is 11.53 days), while in 2019, it varied in the range of 3.25-56.61 days (average value is 22.50 days). At higher sludge ages, there is a greater risk of bulking sludge formation which influences poor settling behaviour of the sludge. But also, at the same time, the higher degree of biological degradation occurs since highly specialised bacteria can accumulate in the system. Thus, the removal efficiency during 2019 is higher compared to 2018.

It is evident that the F/M ratio is showing the opposite trend of sludge age (Fig. 8). With increasing F/M ratio, the sludge age decreases; thus correlations lines have a negative slope.

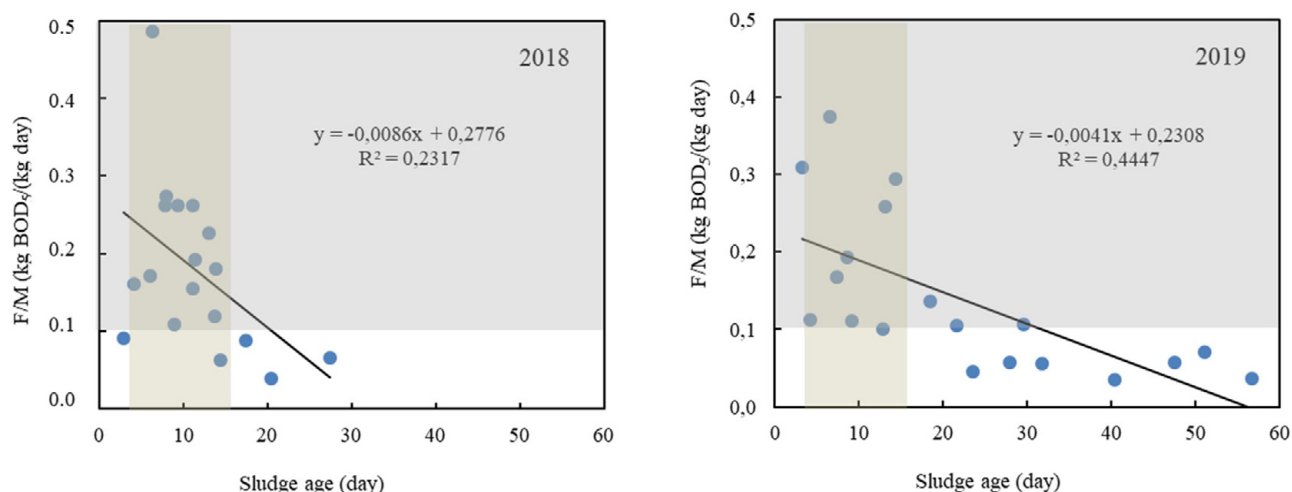


Fig. 8. Food-to-microorganism ratio (F/M ratio) vs. sludge age. Note: the two shaded areas represent the optimal values of sludge age in the range between 3 and 15 days and optimal values of F/M ratio in the range of 0.1-0.5 kg BOD₅/(kg day).

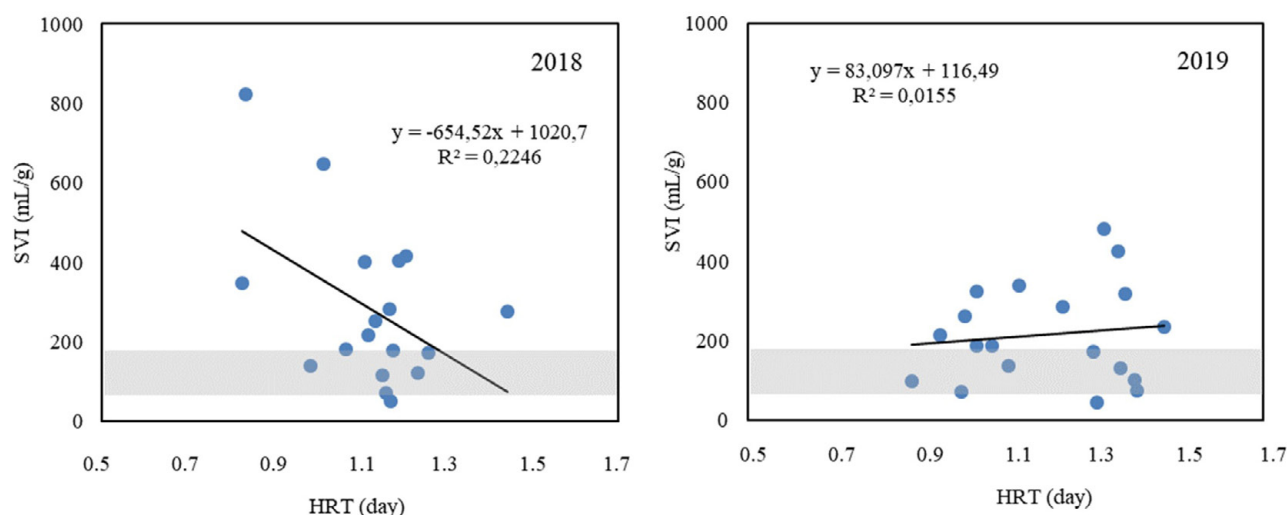


Fig. 9. Sludge volume index (SVI) vs. hydraulic retention time (HRT).

Hydraulic retention time analysis

The hydraulic retention time (HRT) corresponds to the average time of holding wastewater within a controlled volume of the basin. It is calculated by dividing the volume of aeration tank and flow rate. Change in HRT may affect biological activity. Lower HRT affects nitrification, while higher HRT favours nitrification and solubilisation of colloids and particulate BOD (James et al., 2015). Figure 9 compares the SVI index and HRT.

It is evident that HRT range during 2018 varied between 0.83 and 1.44 days (mean value 1.13 days), while during 2019, the values of SVI are less scattered and were between 0.88-1.47 days (mean value 1.20 days). In wastewater treatment systems, the HRT influences the treatment efficiency and is therefore an important design parameter. According to Tchobanoghus et al.

(2003), the HRT is also the mean cell residence time when there is no cell recycling and is suggested to be 2–5 days for COD removal from domestic wastewater. Thus, the HRT needs to be adjusted on higher values, in order to prevent the washout of the sludge (the bacteria, granules and other components) along with water. Otherwise, the degrading bacteria population in the reactor would decrease with time, which will affect the efficiency.

Analysis of biodegradability

The BOD₅/COD ratio can be used as a useful indicator of biodegradability of wastewater. If the BOD₅/COD is <0.1, the wastewater is considered readily biodegradable, and for a BOD₅/COD ratio > 0.5, the wastewater is considered readily biodegradable.

Table 3. Comparison of treatment plant reliability factor (RF) and equivalent number of inhabitants (ENI) of the WWTP Ljubuški calculated for 2018 and 2019.

Year	Quality indicators of treated wastewater	Average concentration of pollutant indicators in wastewater, mg/L	The plant reliability factor (RF), -	Equivalent number of inhabitants (ENI), -
2018	COD	34.38	0.28	3089.55
	BOD	8.98	0.36	
	TSS	5.19	0.15	
2019	COD	27.66	0.22	4202.36
	BOD	5.95	0.24	
	TSS	4.78	0.14	

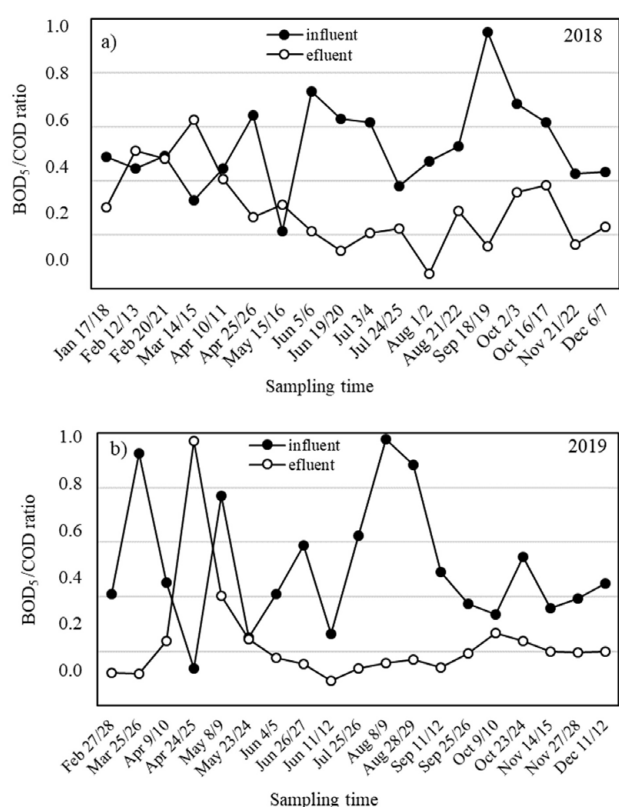


Fig. 10. BOD₅/COD ratio in the influent and effluent at the WWTP during years: a) 2018 and b) 2019.

From Figure 10, it is evident that BOD₅/COD ratio in the influent is varying, which is a consequence of wide variations in influent wastewater composition. The BOD₅/COD ratio during 2018 in influent had a range of 0.21–0.95, with an average value of 0.53, while in effluent, significant reduction in this ratio is evident, and ranged from 0.05 to 0.63, with an average value of 0.29.

During 2019, variations of BOD₅/COD ratios were significant. In the influent, variations ranged from 0.14 to 0.98, with an average value of 0.51, while effluent variation ranged from 0.09 to 0.97 with an average value of 0.23. Max value of BOD₅/COD ratio in the effluent is observed in the sample from April 24th/25th 2019, which relates to significantly higher values of COD in influent (COD equals 1,534 mg/L), which influence lower BOD₅ removal percentage, and BOD₅ remained in the effluent.

Average values of BOD₅/COD ratio in the influent are > 0.5 during both years, which indicate that municipal wastewater composition is considered readily biodegradable. According to Kumar et al. (2010), the BOD₅/COD ratio of domestic wastewater is usually in the range of 0.4–0.8.

BOD₅ and COD correlation

BOD₅ and COD values vary depending on the characteristics of the raw sewage entering the WWTP. However, to optimise working condition during treatment, it is useful to define the correlation between these two parameters.

Correlation between influent COD and BOD₅ was better in 2018 ($R^2=0.8122$). During 2019, correlation is poor compared to 2018, which is a consequence of significant oscillation in raw wastewater composition (Fig. 11).

Removal efficiency

The removal efficiency based on COD, BOD₅ and TSS was calculated according to Equation (1) (Vitez et al., 2012) and the results are shown in Figure 12.

Significant reduction in COD, BOD₅ and TSS is evident in effluent in both years. Small discrepancy for BOD₅ removals was observed in March 2018 and May 2018, for COD in May 2018 and in April 2019, and for TSS in May 2018 and November 2019.

During 2018, COD removal percentage was between 79.46 and 95.07%, with average values at 88.65%; BOD₅ removal percentage was between 69.61 and 98.60%, with average values of 92.32%, while TSS removal percentage was 89.66–98.58%, with average values at 94.72%. Slightly better results of removal efficiency were observed during 2019. COD removal percentage was 83.45–98.39%, with average values at 93.21%; BOD₅ removal percentage had a range of 88.68–99.21%, with an average value of 96.67%; TSS removal percentage ranged between 83.56 and 99.54%, with an average of 95.24%.

From average values of removal percentage, it is evident that percentage of removal efficiency is in the order of TSS > BOD₅ > COD during 2018, while in 2019, percentage of removal efficiency is in the order of BOD₅ > TSS > COD. However, better values of removal efficiency for all three parameters are obtained in 2019, which is connected to lower oscillation values of MLSS and SVI index.

BOD₅ removal percentage is higher than COD which indicated a relatively higher proportion of non-biodegradable content in treated effluent than in raw water. But final values are sig-

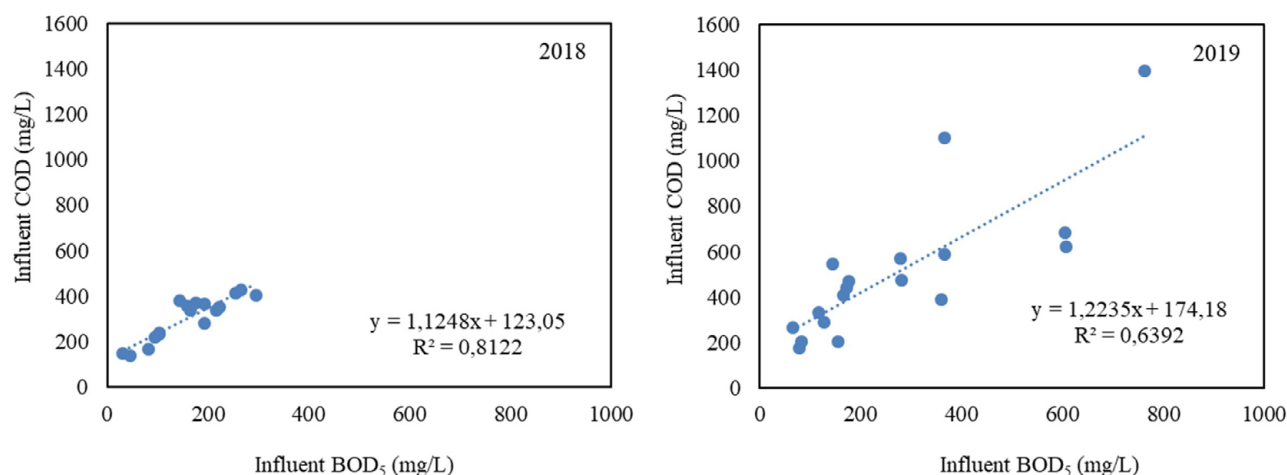


Fig. 11. COD vs. BOD₅ correlation.

nificantly below the limits for BOD₅, COD and TSS according to B&H regulation (Regulation FBiH 26/20). Also, the requirement of achieving the minimum percentage reductions prescribed by B&H regulation (percentage for BOD₅, COD and TSS removal is given in Table 1) is also fulfilled.

Plant reliability and actual efficiency

Comparison of treatment plant reliability factor based on BOD₅, COD and TSS values, and ENI values of the WWTP in Ljubuški during 2018 and 2019 is given in Table 3.

The values of calculated plant reliability factor are significantly below 1.0 for all pollutant indicators (BOD₅, COD and TSS), which confirms proper operation of the WWTP. Moreover, the average values of each indicator were significantly lower than permissible values. The best RF is obtained with TSS, while better plant reliability is obtained for 2019.

The WWTP Ljubuški is intended for the secondary treatment of a capacity of 6,000 PE (population equivalent or equivalent number of inhabitants, ENI). However, the calculated ENI values (Table 3) are below the project value, which indicates that this WWTP can receive additional quantities of sewage for treatment. However, due to negative trends in population growth (mainly to emigration characteristic for this region), it may adversely affect the operation of the plant. This should be taken into account to provide the measures for extending the sewage system to the entire city and suburbs.

Economic cost

During the operation of the WWTP with activated sludge process, besides good treatment efficiency, the operational cost connected with electric current consumption needs to be evaluated and optimised (Haslinger et al., 2016; Balmer, Mattsson, 1994). Electric current consumption by aerators and pumps during 2018 was varying between 13,520 and 16,063 kWh monthly, while during 2019 was in the range between 12,868 and 15,772 kWh monthly, respectively. Taking into account the wastewater flowrate, average operational costs during both years equal 0.455 kWh/m³ of

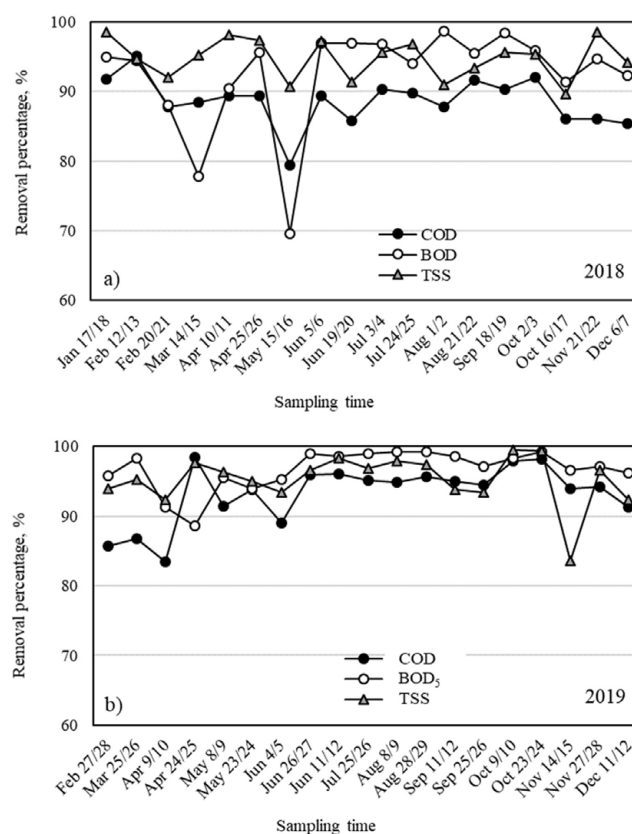


Fig. 12. COD, BOD₅ and TSS removal percentage at the WWTP during years: a) 2018 and b) 2019.

treated wastewater. This is in agreement with an electricity consumption published in reference and equals 0.3–2.1 kWh/m³ for treated wastewater (Altin et al., 2020). However, future operation of wastewater treatment plants needs to be upgraded to mitigate electricity cost and to make overall processes more cost-effective.

Conclusion

In this study, a comprehensive analysis of treatment efficiency of a small-scale WWTP in Ljubuški was performed for two years, 2018 and 2019. The results show that wastewater loading with dispersed matter is almost three times lower compared to load of wastewater with COD. Evidently, the composition of municipal wastewater entering the WWTP is highly influenced by the discharge of wastewater with a substantial amount of non-biodegradable soluble organic matter into sewage, as well as septic tank solids from household, which influence significant variations of BOD₅, COD and TSS values in influents. Average values of BOD₅/COD ratio in influent are > 0.5 during both years, while correlation between influent COD and BOD₅ was better in 2018 (R²=0.8122).

The characteristics and biodegradability of raw wastewater compositions are influencing on their fate in a WWTP with activated sludge. Oscillation of MLSS and SVI values in activated sludge is observed as well as oscillations of design parameters such as F/M ratio, sludge age and HRT outside of optimal values. Lower values of the MLSS are influencing on settleability and compactability of the sludge. Correlation between F/M ratio and SVI is quite poor, as well as correlation between sludge age and the MLSS even reducing the sludge age with reduce in the MLSS was evident. The HRT needs to be adjusted on higher values.

Removal percentage is in the order of TSS > BOD₅ > COD during 2018, while in 2019 is in the order of BOD₅ > TSS > COD. The calculated plant reliability factor based on COD, BOD₅ and TSS values confirm proper operation of the WWTP. Calculated ENI values are below the project value, which indicates that the WWTP can receive additional quantities of sewage for treatment. Average operational costs during both years equal 0.455 kWh/m³ of treated wastewater and are within the values published in reference. The obtained results can be very useful in obtaining optimal process controls of the WWTP in Ljubuški as well as for comparison of the treatment efficiency with other wastewater treatment plants.

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