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Slaughterhouse water consumption and wastewater characteristics in the meat processing industry in Serbia

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ABSTRACT

The aim of this paper is to present the current state of slaughterhouses in Serbia regarding water consumption, wastewater flows and their characteristics, their current relationship with the environment and compare them with related plants in terms of wastewater qualities and concentrations of pollutants in them. The survey was conducted on a sample of 41 slaughterhouses. It has been concluded that a large number of slaughterhouses (24 of them) do not perform any wastewater treatment before their discharge into appropriate recipient and it is also concluded that the slaughterhouses that perform wastewater treatment generally do not reach the emission limit values of pollutants, which is confirmed by the results of physical and chemical testing. Slaughterhouses wastewater quality parameters were analyzed with Statistical Package for the Social Sciences. The average value of pH (7.24 ± 0.69) of discharged wastewater is within the allowed range, but the samples have higher chemical oxygen demand and biochemical oxygen demand content (17 and 12 slaughterhouses exceeded the allowed limit values, respectively). total suspended solids (TSS) and fat, oil and greases (FOG) are mainly within allowed ranges, but there are some slaughterhouses that have higher values for TSS (six) and FOG (five) slaughterhouses exceeded the allowed limit values. TSS is extremely significant parameter because suspended solids can lead to the development of sludge deposits and anaerobic conditions when untreated wastewater is discharged in the aquatic environment.

Keywords: Meat processing industry; Slaughterhouse; Questionnaire; Water; Wastewater

1. Introduction

The functioning of any factory in the food industry, including the meat industry, cannot be imagined without the use of water. Meat processing plants and slaughterhouses are known for being the big consumers of water [1] and big generators of wastewaters [2] and thus cause environmental degradation [3]. The amount of water used in slaughterhouses and meat processing plants is linked to the number of slaughtered animals.

In slaughterhouses, the water is used for sanitary, processing (starting from the first step when the live animal enters the facility, until the last step when meat products are dispatched from the meat processing plant [4]), and technological purposes (plant washing, steam production, production of hot water, compressor cooling and production of ice water [5]). Water is used primarily for carcass washing after hiding removal from cattle, calves, and sheep or hair removal from pigs and again after evisceration, for cleaning, and sanitizing of equipment and facilities, and for cooling of mechanical equipment such as compressors and pumps

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including carcass blood washing, equipment sterilization, and work area clearing. Also, a large amount of water is used for different operations such as hog scalding [6].

Most of the published studies/research related to water consumption, wastewater generation and wastewater characteristics in the meat industry (slaughterhouses and meat processing plant) were focused on: (1) minimization of water consumption and minimization of wastewater generation, and (2) applying modern (combined) treatments for wastewater treatment [7–11].

A large number of conducted studies and research start from defining the places of wastewater generation and their characteristics [12]. In order to identify places of wastewater generation, it is necessary to identify water consumption centers in slaughterhouses and meat processing plants. Given the wide range of differences that can be expected when determining where freshwater is used in slaughterhouses, it is more efficient to examine the specific processes in which freshwater is used. Table 1 shows the percentage use of freshwater in specific processes in different slaughterhouses.

After defining the place of use of freshwater, it is necessary to determine the characteristics of wastewater from slaughterhouses and meat processing plants.

Slaughterhouses wastewater (SWW) has a large variation in pH, chemical oxygen demand (COD), biochemical oxygen demand (BOD_5), total suspended solids (TSS), fat, oil and greases (FOG) and other parameters [1,4,17,18]. They also contain high amounts of organic material and consequently high BOD and COD values due to the presence of blood, tallow and mucosa. Meat industry wastewater may also have a high content of nitrogen (from blood) and phosphorus, as well as TSS [7,19]. To summarize, slaughterhouses and meat processing plants are part of a large industry worldwide, where the composition of the wastewater depends on the diverse practices in the slaughtering process. Consequently, SWW requires significant treatment for a safe and sustainable release to the environment [20]. In correlation with previous, many authors and researchers were following and describing the characteristics of SWW. Table 2 summarizes the results of the characteristics of SWW from various studies and research. The variation of the strength and characteristics of slaughterhouse wastewater is caused by several factors such as production capacity, type, and weight of an animal, methods of transportation, animal receiving, and holding, processing technology, amount of carcass, washing temperature, cleaning and sanitizing procedure, and labors behavior [21].

In order to fulfill emission limit requirements and to protect the environment, slaughterhouses can use the two following techniques: minimizing freshwater consumption (FWC), waste and wastewater treatment.

Minimizing water consumption implies optimization of its use or water management. Numerous papers have been published worldwide with this topic. Bustillo–Lecompte and Mehrvar have described the treatment processes and gave a few examples of their applications [12]. Few advances are accounted for in terms of minimization of waste and reduction of water use, reuse and recycling, which may offer new alternatives for cost-effective waste management. Casani, Rouhany, and Knøchel in [27] discuss about the implementation of water reuse practices in the food industry. Reuse of water presents a great challenge for both companies and public health authorities regarding knowledge, technical expertise, and documentation. Formulation of guide-lines addressing water reuse, research and development on relevant aspects and collaboration between academia, food processors and regulatory agencies are required for facilitating

Table 1
Consumption of fresh water in specific processes in different slaughterhouses

	Slaughterhouse [%]					
Area of usage	Sl. 1	Sl. 2	Sl. 3	Sl. 4	Sl. 5	Sl. 6
Vehicle wash	–	–	–	7	5	5
Stockyards	25	7–24	7–22	6	5	3
Slaughter, bleeding, evisceration	10	49–79	44–60	10	5–10	31
Cutting, deboning	–	5–10	–	5	5–10	–
Scald tank	–	–	–	13	3	7
Rind treatment	–	–	–	–	10–15	–
Casing	–	–	9–20	–	20	–
Paunch, gut and offal washing	20	7–38	7–38	–	–	–
Rendering	2	2–8	2–8	–	–	–
Sterilizers, wash stations	10	–	–	–	10–15	5
Amenities	7	2–5	2–5	–	–	–
Plant cleaning	22	–	–	46	15–20	33
Chillers	2	2	2	1	5	–
Cooling	–	–	–	12	–	6
Boiler losses	2	1–4	1–4	–	2	–
Personal hygiene	–	–	–	–	–	10
Source	[13]	[13]	[14]	[15]	[15]	[16]

Table 2
Comparison of SWW characteristics

Parameter	Sl. 1 (2016)	Sl. 2 (2011)	Sl. 3 (2011)	Sl. 4 (2010)	Sl. 5 (2010)	Sl. 6 (2009)	Sl. 6 (2008)
COD (mg/L)	4,407	5,817 ± 473	3,756 ± 687	2,144	208–2,430	1,100–15,000	1,962
BOD_5 (mg/L)	1,800	2,543 ± 362	1,873 ± 421	1,235	160–977	600–3,900	1,080
pH (–)	6.8	7.31 ± 0.12	7.19 ± 0.06	6.69	–	5–7.8	–
TSS (mg/L)	1,703	3,247 ± 845	1,171 ± 311	863	50–983	220–6,400	–
FOG (mg/L)	–	34 ± 9	–	–	–	40–1,385	–
Source	[18]	[22]	[21]	[23]	[24]	[25]	[26]

the process of implementation of water reuse practices in the food industry. All possible ways of minimizing the use of freshwater in the production process of meat production are considered in [28].

The methods of wastewater treatment from slaughterhouses and meat processing plants are similar to current technologies used in the treatment of municipal wastewater. For the purpose of wastewater treatment, the following methods are available: mechanical or prior (primary) treatment, biological or secondary treatment and physical and chemical (tertiary) treatment. These include lagoon and ponds systems, sedimentation and floatation, coagulation/flocculation, adsorption, membrane technology, dissolve air and other advanced oxidation processes. However, several researchers have specifically reported different methods of slaughterhouse wastewater treatment that works as an entity and a combined operation [29].

Bustillo-Lecompte and Mehrvar presented models of wastewater treatment by combined anaerobic and aerobic processes for biogas production and organics removal could be bused as a base for future studies for the reduction of operating costs while providing high-quality treated wastewater for water reuse in the meat processing industry [30]. Baddour et al. [31] considered effective and economical ways to treat slaughterhouses wastewater, based on reducing the concentration of organic loads to an appropriate level, preserves environs and reduces treatment costs for owners of industrial plants without augmenting investment costs. In [32], the effectiveness of the wastewater treatment by dissolved air flotation (DAF) followed by advanced oxidation process (AOPs) using H_2O_2/UV and photo-Fenton reactions were evaluated on a laboratory scale. The results have shown that the DAF treatment efficiently reduced the COD, color, turbidity and total solids contents. These results show that the DAF process followed by an AOP process might be efficient for meat wastewater treatment, intended or not to water reuse purposes. In [33] anaerobic and coagulation–flocculation hybrid process was explored in a laboratory pilot scale for removal of contaminants from a slaughterhouse effluent. The results showed that the anaerobic and coagulation–flocculation hybrid process does not meet environmental standards to dispose of wastewater and requires a supplementary treatment process. In [25], numerous case studies are described to bestow maximum understanding of the wastewater characteristics, kind of treatment employed, and complications involved in managing and treating slaughterhouse effluent.

The common technologies used for the treatment of wastewater from slaughterhouses and meat processing plants are given by document BAT 2005. According to this document, there is a primary, secondary and tertiary treatment for treating slaughterhouse wastewater [15]. Different types of technologies are used for the treatment and removal of emissions. In Seville, Spain on 24–27 June 2019, the technical working group for the review of the Reference document on best available techniques for the slaughterhouses and animal by-product industries held their first plenary meeting. In a report of this meeting, it is concluded that it is necessary to include the combined treatment of wastewater from different origins in the scope of the previous document [34].

1.1. Slaughterhouses in the Republic of Serbia

The meat industry is one of the leading food sectors in Serbia, with total annual meat production around 450 thousand tones [35,36]. In the meat processing and preserving sector, there are large variations by years. The largest meat production of almost 80,000 tones was achieved in 2015. The number of slaughterhouses varies depending on the criteria, that is, whether the slaughterhouse is only registered as operating a limited number of working days per year or is considered as a fully operating slaughterhouse slaughtering at least 3 d a week [37]. The analysis of the current situation showed that this sector consists of approximately 442 slaughterhouses and meat processing plants. About ten slaughterhouses and meat processing plants are industrial and their processing capacity is significantly higher than the existing production. The largest numbers of processing facilities are represented by butchers and slaughterhouses. These categories have a small slaughter volume, low processing rate and low business turnover [38].

Based on data from the Statistical Office of the Republic of Serbia, Table 3 presents the values of slaughtered animals by type (cattle, pigs, sheep). The table shows that the largest number of pigs, afterward sheep and finally cattle are slaughtered in the last 3 y. Also, Table 3 shows that the number of slaughtered animals has a declining trend during the observed period [39].

The meat processing industry in Serbia has started to invest in increasing capacity, standards and technology. Only a few companies have achieved EU standards and comply with legal requirements [41]. In the Republic of Serbia, many slaughterhouses record significant water consumption resulting from outdated technological processes and technologies. However, environmental costs are not significant at this time. The significance and value of these costs will

Table 3
Livestock slaughter in Republic of Serbia [40]

Year	Animals × 10^3 (t)					
	Slaughtered cattle		Slaughtered pigs		Slaughtered sheep	
	Total	In slaughterhouses	Total	In slaughterhouses	Total	In slaughterhouses
2016	324	170	5,853	2,212	1,630	78
2017	284	178	5,706	2,079	1,552	104
2018	325	173	2,217	101	1,541	118

increase with the accession to the EU and the adoption and implementation of environmental regulations [38].

There is a lack of data regarding the total number of meat industry facilities in Serbia that have wastewater treatment. The information about the quality and quantity of wastewater generated in slaughterhouses and meat processing plants is also unknown [3]. Although this type of wastewater is biodegradable and therefore relatively easy to treat, in Serbia it is often discharged into sewage and surface water without prior treatment. These trends have major consequences on environmental contamination and human health, as well as on the establishment of good wastewater management practices in Serbia [42].

1.2. Permitted emission limits for pollutants in wastewater from slaughterhouse in the Republic of Serbia

The Government of the Republic of Serbia adopted a Decree on the emission of limit values of pollutants in surface waters and the city sewage systems (including septic tanks) [43]. Because of it, slaughterhouses are obliged to purify wastewater resulting from the meat processing before discharging it.

Table 4 compares and describes the standard levels and limit values of organic constituents prescribed by the World Bank Group, the Council of the European Communities and the Republic of Serbia to be discharged into the urban sewage system (including septic tanks) or surface waters.

Fig. 1. Locations of researched slaughterhouses and meat processing plants.

2. Material and methods

The methodology included the following steps:

- First, the authors contacted about 70 slaughterhouses and meat processing plants, and after that a questionnaire via e-mail was sent. Data collection began in December 2018 and ended in March 2019. 41 respondents (slaughterhouses and meat processing plants) answered the questionnaire from five municipalities within Serbia: Sabac, Valjevo, Pozarevac, Kragujevac and Leskovac (Fig. 1).

The questionnaire was related to production capacity, water consumption, places of wastewater generation and their quantity, monitoring of water flows and characteristics of wastewater.

Table 5 presents the production capacity of those 41 respondents.

The most important questions from the questionnaire for the research area of this paper are:

- From where is the freshwater supplied?
- Where is the wastewater discharged?
- Is the wastewater treated before discharge?
- Which method is used for wastewater treatment?
- How many times during the year is the sampling of wastewater done?

In addition to the questionnaire, the physical and chemical characteristics of the wastewater were obtained from these companies. Accredited testing laboratories on the territory of Serbia conducted physical and chemical wastewater tests that included quarterly monitoring of parameters using test methods regulated by the Serbian standards and

Table 4
Comparison of standards limits of World Bank, EU and Serbia for slaughterhouse wastewater depending on the type of recipient

Parameter	World Bank		EU		Serbia	
	Sewage and septic tanks	Surface waters	Sewage and septic tanks	Surface waters	Sewage and septic tanks	Surface waters
COD (mg/L)	N/A	125	N/A	125	450	110
BOD_5 (mg/L)	N/A	30	N/A	25	300	25
pH (–)	N/A	–	N/A	–	6.0–9.0	6.5–9.0
TSS (mg/L)	N/A	50	N/A	35	500	35
FOG (mg/L)	N/A	–	N/A	–	40	–
Source	[44]		[45]		[46]	

Table 5
Capacity of the sampled companies

Capacity (t/d)	Sample (N)
0–5	17
5–10	19
10–15	3
15–20	–
20–30	2

legislations [46] SWW should be tested at least four times a year.

- The next phase involved the processing of the data obtained from the questionnaire and testing on the field. Testing was conducted in four slaughterhouses in the territory of the city of Kragujevac and its surroundings. For the purposes of this research authors interviewed responsible persons of slaughterhouses (in some cases information was obtained from multiple responsible persons). Testing on the field was conducted during working days when the production process was in progress.

Based on testing on the field and based on a visiting slaughterhouse (four of them) in the territory of the city of Kragujevac and its surrounding area, freshwater consumption centers and wastewater production center (WWPC) in slaughterhouses were identified.

Fig. 2 shows a general flowchart of the production process in slaughterhouses in Serbia. In the figure, processes are divided according to water consumption. As seen from the figure most of the processes require FWC, some of them require high consumption of water, and only three processes do not require FWC.

Most of these companies monitor FWC only at the whole enterprise level, while FWC is not tracked in meat production processes. This means that there is no monitoring of FWC by production lines. Therefore, it can be said that existing companies are not aware of the amount of freshwater consumed and what is its share in total production costs.

Wastewater occurs from different sources during the production process. By monitoring the production process on-site wastewater production places were identified. In different stages of the production process in slaughterhouses in Serbia, a significant amount of wastewater is produced. Fig. 3 presents the different stages of the production process with wastewater sources.

- Finally, a statistical analysis of the data collected during the slaughter survey was made. The independent variables were: capacity of a slaughterhouse and wastewater with or without treatment. The dependent variables were physicochemical parameters of the wastewater such as BOD_5, COD, TSS, FOG and pH.

3. Results and discussion

3.1. Freshwater consumption

FWC, in general, varies from a slaughterhouse to slaughterhouse and mostly depends on its capacity, and also from the production program. Factors that also contribute to the freshwater consumption are the hygienic condition of the animals brought to the slaughterhouse, the period of keeping animals before their slaughter, the condition of the equipment and its age, and from staff training. Based on authors research, it was concluded that distribution of water consumption by operations in the tested slaughterhouses in Serbia was 22% for slaughter, bleeding, and evisceration, 10% for cutting and deboning, 15% for scald tank, 5% for amenities, 45% for plant cleaning and 3% for cooling.

The FWC analysis was performed on the observed sample for slaughterhouses supplied with freshwater from the city water supply networks only (36 slaughterhouses, or 88% of the analyzed sample, while 5 slaughterhouses are supplied with freshwater from wells, or 12%). The analysis does not cover slaughterhouses that use freshwater from their own wells, since in that case there are no related FWC costs, and therefore no measurements of FWC are performed or available.

Fig. 4 shows the annual consumption of freshwater in one slaughterhouse in the Republic of Serbia. This slaughterhouse is engaged in the production of meat products from different animals (cattle, pigs, sheep, etc.). FWC is monitored only at the entrance to the plant. The maximum measured water consumption in one month is 1,57,000 L.

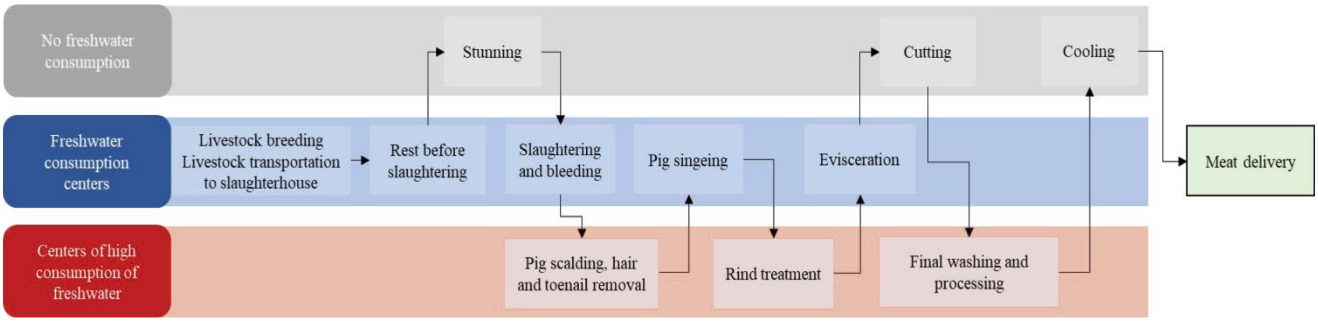

Fig. 2. General flowchart of the production process in slaughterhouses in Serbia with processes divided according to water consumption.

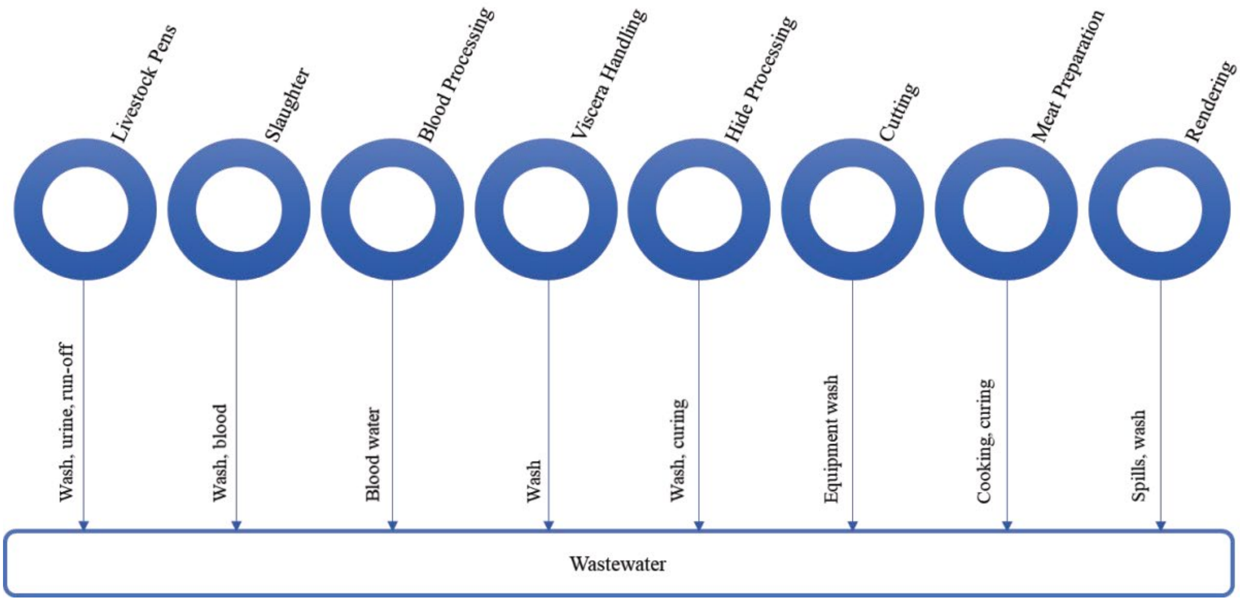

Fig. 3. WWPC in pig slaughterhouse.

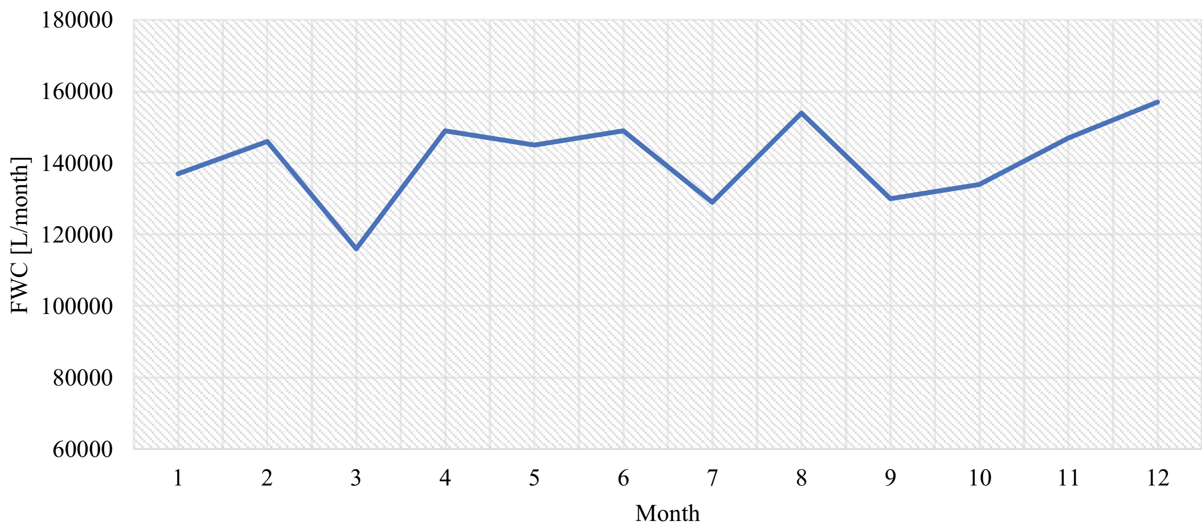

Fig. 4. Annual FWC in one slaughterhouse in the Republic of Serbia.

Fig. 5 presents the dependence of FWC on the number of slaughtered animals during the one month in one slaughterhouse in the territory of Serbia which has a combined production.

FWC at the monthly level in the mentioned slaughterhouse is very irrational and is not justified by the production program. This is confirmed by the coefficient of determination ($R^2 = 0.2137$) and the amount of freshwater that neither contributes to the production process nor the number of slaughtered animals (2,32,550 L/month).

When the FWC is divided with the number of slaughtered animals in the slaughterhouse, another important indicator of the functioning and operation of the slaughterhouse is obtained. That indicator is a specific freshwater consumption (SFWC).

SFWC according to the number of slaughtered animals is presented in Fig. 6. SFWC from slaughterhouses and meat processing plants in this study is around 360–560 (l/head). Comparing those values with other studies [47] and [48] the range of SFWC in Serbia are similar to in the other slaughterhouses.

As previously said, for slaughterhouses, the key environmental issue, among others, is FWC [15]. Given the wide range of differences that can be expected when benchmarking freshwater usage in slaughterhouses, it is likely to be more effective to examine the specific processes where the freshwater is used.

The required amount of freshwater is higher in the case of a mechanized system than manual slaughter. FWC also varies depending on the size of the slaughterhouse, that is, large slaughter requires less freshwater compared to small slaughterhouses for large animals [49].

3.2. Wastewater generation in the production process and their treatment

The analyzed sample shows that the dominant recipients, for discharged SWW, are systematic urban drainage systems and septic tanks. 29 slaughterhouses discharge wastewater into septic tanks (71%), 11 slaughterhouses are discharged into the city sewage system (27%), and only one slaughterhouse discharges their wastewater into surface waters (2%). The positive fact is that of 41 samples, only 1 sample discharges wastewater into surface waters. SWW contains organic pollution and the discharge of such wastewater into surface waters, without any treatment, can cause adverse effects to the aquatic ecosystem.

When it comes to the treatment of wastewater in the analyzed sample, more than half of the slaughterhouses (24 of them or 59%) do not perform any wastewater treatment at the exit from the plant, while 17 of them perform some treatment (41%). Treatments are mainly reduced to the primary purification (performed by 17 slaughterhouses–36%). Secondary purification is performed by six slaughterhouses (5%), while tertiary treatment is not present in any slaughterhouse. This confirmed the fact that slaughterhouses are classified as a group of large sources of water pollution. Based on the analysis so far, it can be concluded that the situation in the Republic of Serbia regarding the treatment of SWW is bad, as there are a large number of registered slaughterhouses that do not treat wastewater. In addition, it can be concluded that wastewater with high pollution levels is released into the recipients.

3.3. Results of physical and chemical wastewater testing

As with all other sectors of the food industry, and in this sector it is necessary to test the quality of wastewater. The analysis showed that the number of sampling and testing per year varies between slaughterhouse. The number of sampling and testing in slaughterhouse during the year is zero (2%), I (37%), II (29%), III (15%), IV (15%) and V (2%). The largest number of slaughterhouses examine the quality of wastewater 2 or 3 times during the year. As an example of good practice, there are also slaughterhouses that release the quality of wastewater up to five times during the year. On the other hand, the analysis showed that there are slaughterhouses that do not examine the quality of wastewater. These slaughterhouses release their wastewater without any treatment into the recipient.

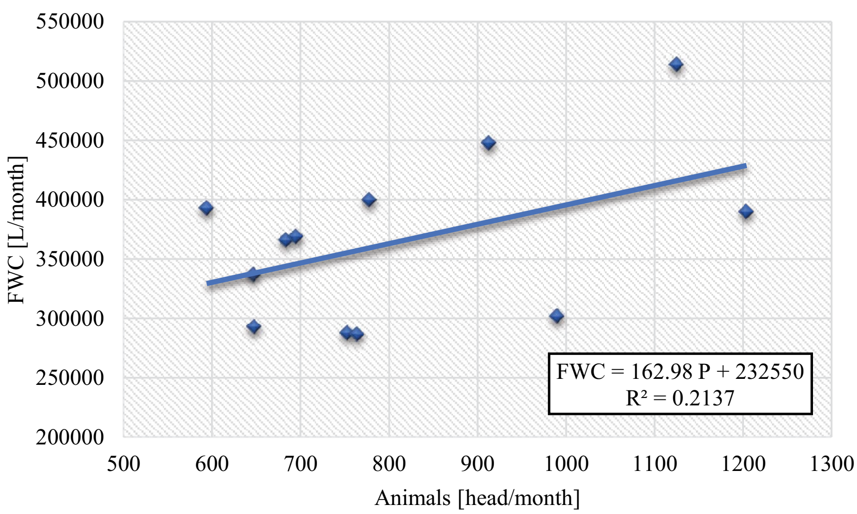

Fig. 5. FWC in the function of slaughtered animals in one slaughterhouse in Serbia.

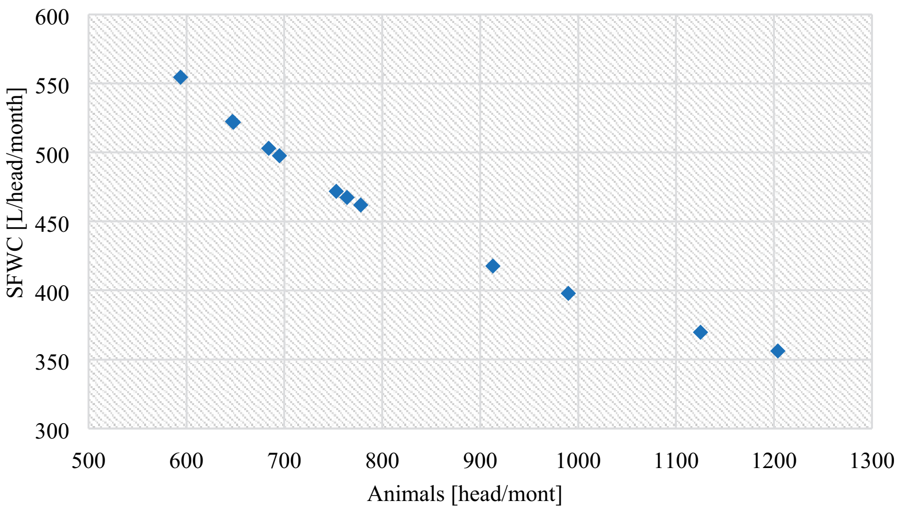

Fig. 6. SFWC in the function of slaughtered animals in one slaughterhouse in Serbia.

Slaughterhouse wastewater is characterized in terms of its physical, chemical and biological properties. This study gives wastewater chemical characteristics such as pH, BOD_5 COD and FOG, and physical characteristics such as TSS.

For slaughterhouses that discharge their wastewater into the sewage system or septic tanks, the results of pollutant emissions are presented in Figs. 7–12. The presented values are wide-ranging. These values do not indicate an error in the analysis or a better or worse management of the production process. The differences between values are due to the moment of sampling.

Descriptive statistics were used to identify the characteristics of each measured parameter in terms of central tendency and dispersion. Central tendency provides the location of the distribution for each parameter including the mean, while dispersion measures the spread in the data set including the standard deviation, minimum and maximum. For the specified slaughterhouse, wastewater parameters minimum, maximum, mean value, and standard deviation were determined. Table 6 displays the values obtained for parameters from 40 slaughterhouses that discharge their wastewater into sewage and septic tanks (one slaughterhouse discharges its wastewater into surface water). Also, the same table compares obtained values with the required emission limit values specified by the national environmental regulation (Republic of Serbia) [46] related to wastewater, whose pollutants originate mainly from slaughterhouses. In this table, some parameters were found to have very low concentration and others were found to have very high concentration compared to their limiting values during analysis.

The overall mean COD was 977.54 ± 1,147.3 (Table 6). The COD from previous studies [18–26,50] ranged from 208–15,000 mg/L. Of the total number of slaughterhouses surveyed, the value of COD in wastewater discharged into sewage or septic tanks is within the allowed limits for 24 slaughterhouses (COD > 450), while in 17 slaughterhouses the COD value exceeds the permitted limit values. Fig. 7 units the COD values measured in slaughterhouses where their value exceeds the allowed limit values in 2018 (the maximum number of measurements is five times during the year). The figure presents that there are slaughterhouses in which this value drastically exceeds the allowed limit values. The maximum value of COD emitted from slaughterhouses was recorded at the first measurement in slaughterhouse seven and is 4,500 mg/L. Of the total number of slaughterhouses presented in the figure, seven slaughterhouses have the primary treatment of wastewater that reduces the value of this pollutant. 10 slaughterhouses discharge wastewater directly into the sewerage or septic tank with a value of COD, which exceeded the permitted limits.

The overall mean BOD_5 was 434.36 ± 632.63 (Table 6). The value of BOD_5 is affected by meat type, presence of blood and fat [50]. The BOD_5 from previous studies [18–26,50] ranged from 160–4,600 mg/L. The values of BOD_5 for the surveyed slaughterhouses are presented in Fig. 8. Out of the total number of slaughterers, the value of BOD_5 in wastewater discharged into sewers or septic tanks is within the allowed limits in 29 slaughterhouses (BOD_5 > 300), while in 12 slaughterhouses the value of BOD_5 exceeds allowed limit values. The maximum value of BOD_5 emitted from slaughterhouses was recorded at the first measurement in slaughterhouse 5 and is 2,871 mg/L. 8 slaughterhouses discharge wastewater directly into the sewerage or septic tank with BOD_5 whose values exceeded the permitted limits. It can be noted that the values of COD and BOD_5 exceed the allowed concentrations up to 10 times in some cases.

Fig. 9 presents the measured values of pH exceeding the allowed limit values. The limit values of pH in the Republic of Serbia range from 6.0 to 9.0. The overall mean pH was 7.24 ± 0.69. This pH range is comparable to previous studies [18–26,50]. For almost all surveyed slaughterhouses, this value in wastewater ranges within the allowed limits. In 3 slaughterhouses this value exceeds the allowed limit values in wastewater. The maximum value measured is 10. The basic characteristic of wastewater generated in technological processes is the presence of fats and oils, orthophosphates and parameters of microbiological contamination, resulting in poor alkalinity of wastewater.

The overall mean TSS was 162.19 ± 364.96. This TSS range is comparable to previous studies [18–26] ranged

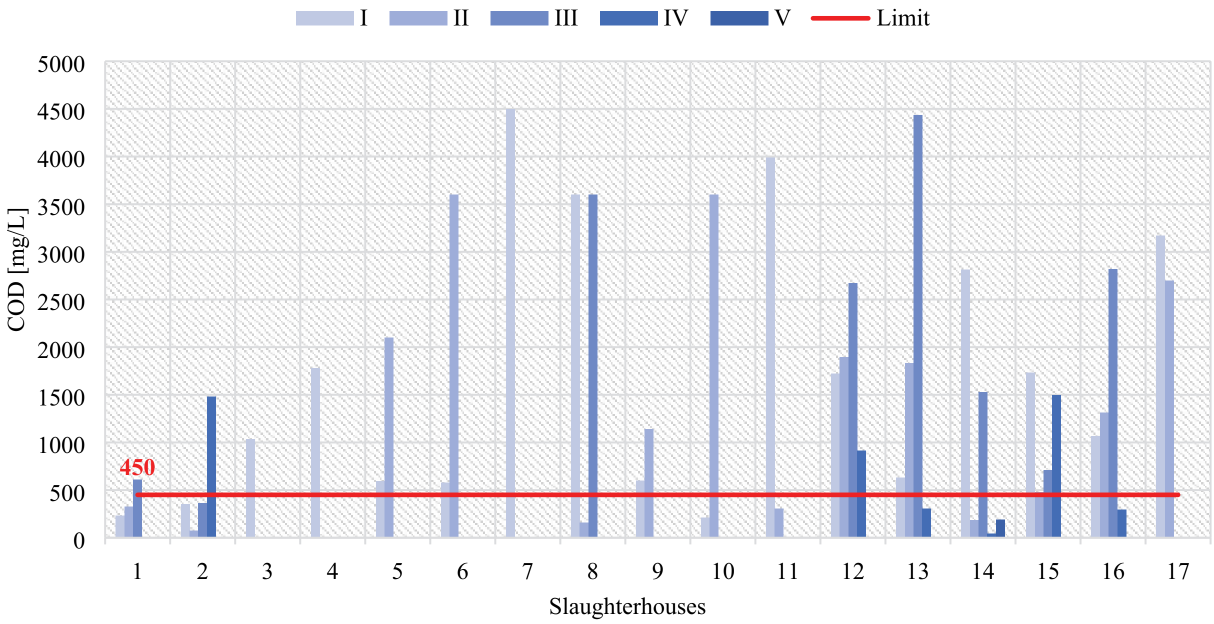

Fig. 7. COD values for slaughterhouses that discharge wastewater into sewers or septic tanks.

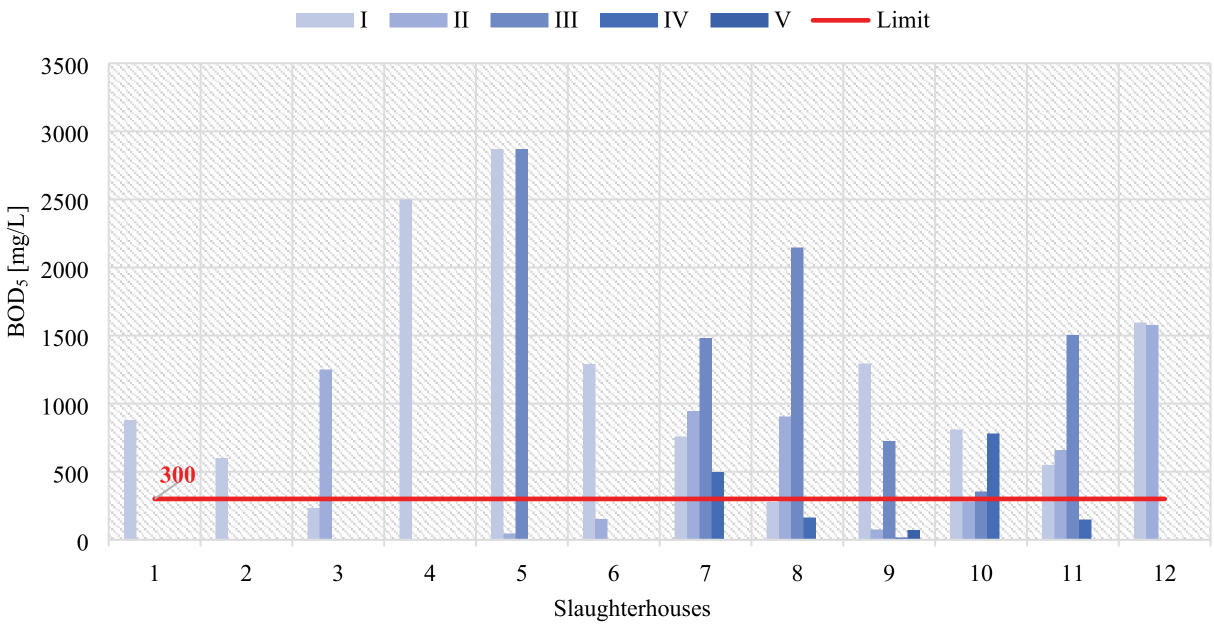

Fig. 8. BOD_5 values for slaughterhouses that discharge wastewater into sewers or septic tanks

from 50–3,247 mg/L. Fig. 10 presents the TSS concentration values exceeding the maximum allowed values. The maximum measured value is 2,138 mg/L, which is four times the allowed limit value (>500).

The largest range of FOG of 40,600 mg/L is found in the study [50]. Fig. 11 presents slaughterhouses whose concentrations of FOG exceed the permissible limit values. The highest measured value of the concentration of FOG in wastewater is 547.6 mg/L. The maximum allowable value of FOG is 40 mg/L for wastewater discharged into sewerage and septic tanks.

The values of TSS and FOG are extremely significant because suspended solids can lead to the development of sludge deposits and anaerobic conditions when untreated wastewater is discharged in the aquatic environment.

Compared to the references given earlier in the introduction [18–26,50], it can be concluded that the characteristics of wastewater in Serbia do not differ much. Comparing mean values of wastewater characteristics without treatment in literature [51] (which are for COD = 5,000 mg/L, BOD_5 = 3,000 mg/L and pH = 6.5) with mean values for wastewater from Serbian slaughterhouses, it was shown that values

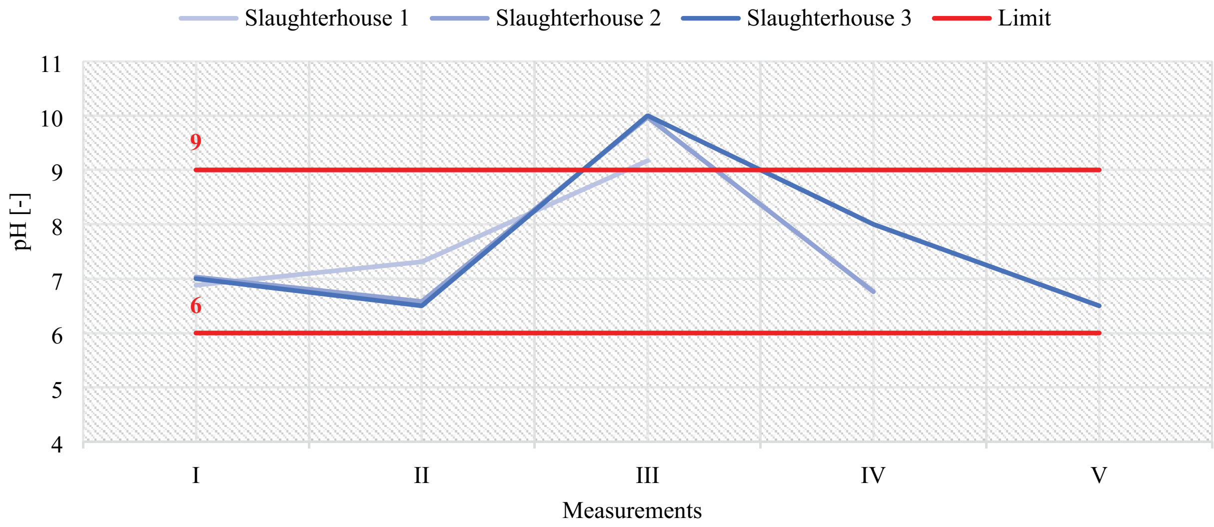

Fig. 9. pH values for slaughterhouses that discharge wastewater into sewers or septic tanks.

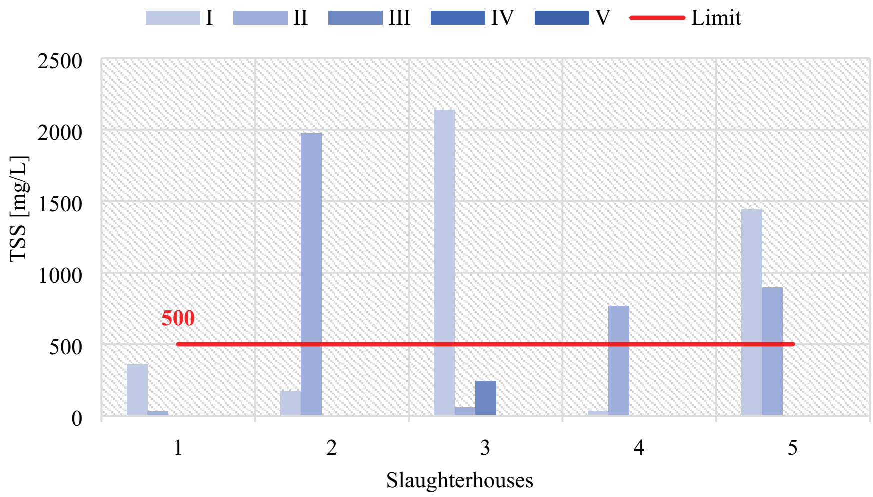

Fig. 10. TSS values for slaughterhouses that discharge wastewater into sewers or septic tanks.

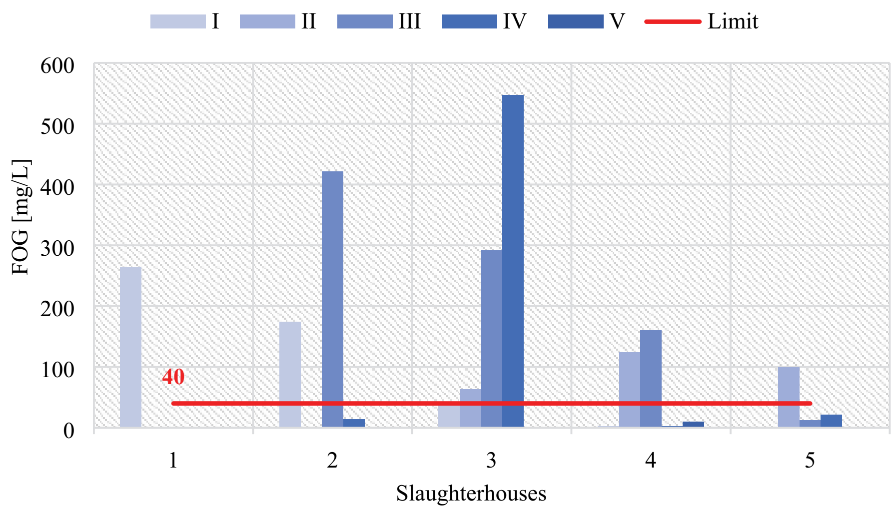

Fig. 11. FOG values for slaughterhouses that discharge wastewater into sewers or septic tanks.

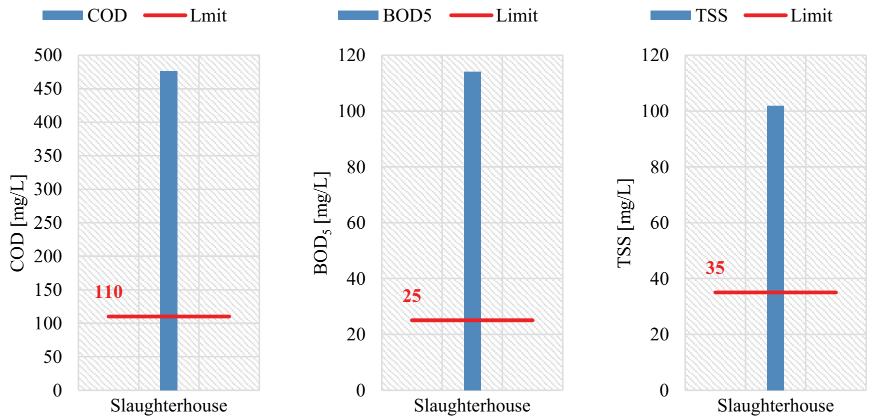

Fig. 12. COD, BOD_5 and TSS values for slaughterhouses that discharge wastewater into surface water.

in Serbia are smaller. However, comparing mean values for COD and TSS in literature [52] with mean values from Serbian slaughterhouses wastewater, it can be concluded that values in Serbian are higher. High BOD values in the wastewater samples might be obtained when fats and vegetable trimmings are discharged together with the processing wastewater [53]. Also, high BOD will disturb organic matter decomposition in the wastewater, which causes suspended solids in the wastewater to fail to be digested under anaerobic conditions [54].

Suitable pH for the existence of biological life is quite narrow and critical and is typically 6 to 9 [18]. In this study, the average value of the pH of discharged wastewater is within that range (7.24 ± 0.69). The samples of the studied slaughterhouses have higher COD and BOD_5 content. The presence of blood and the sample sites had a highly significant impact on the BOD_5 and COD. TSS and FOG are mainly within ranges. There are some slaughterhouses that have higher values for TSS and FOG. TSS is extremely significant value because suspended solids can lead to the development of sludge deposits and anaerobic conditions when untreated wastewater discharged in the aquatic environment [18].

In a survey conducted in 2018, out of 41 slaughterhouses, only one facility releases its wastewater into surface waters. The results of the emission of pollutants in case the surface waters are used as receivers are shown in Fig. 12. This slaughterhouse performs only one time per year sampling and testing of water, which means that these values can variate during the year. From the figures, it can be noticed that the measured values of the COD, BOD_5, and TSS exceed the allowed limit values. The values of pH are in the allowed limit values. This slaughterhouse does not have any treatment of wastewater before the discharge of wastewater into surface water, which means that this facility emits significant concentrations of pollutants in surface waters.

For statistical analysis, Statistical Package for the Social Sciences was used. Conducted tests included the analyses with five parameters: COD, BOD_5, pH, TSS and FOG. Presented results were obtained using Spearman's correlation and Kruskal–Wallis H test.

The correlations between laboratory analysis of physical and chemical characteristics of wastewater were done using Spearman's correlation coefficients (a significance threshold of $p = 0.05$ was retained, Table 7). The established correlation coefficient, ranging from a negative one to a positive one, is the magnitude of the interrelationship in the same direction (positive values) or in the opposite direction (negative values) [55,56].

A strong negative or positive relationship is identified when the coefficient is closer to the absolute value of one. Coefficients closer to zero indicate a weak or nonexistent relationship between the two variables.

The Spearman's correlation test of the data revealed that the wastewater load for COD values correlated with values measuring the presence of TSS ($p < 0.05$). This means that a change in one parameter could account for a certain predictable change in the other parameter. TSS and COD correlation [57,58] showed that the increased TSS/COD ratio is an index that allows us to suspect a phenomenon of resuspension of deposits (phenomena of sedimentation–erosion during transport into a network) and that COD/TSS ratio represents the content of COD in the particles.

Also, a weak correlation was obtained between TSS and BOD_5 ($p < 0.05$), while there is no correlation among other parameters [59]. The strong relationship between BOD_5 and COD ($p = 0.000$) indicate that COD could be used as an indicator of the environmental oxygen load [60].

Scatterplot, Fig. 13, shows a correlation between BOD_5 and COD for various slaughter wastewater. Furthermore, this relation is roughly linear ($R^2 = 0.07789$).

Also, data were analyzed with the Kruskal–Wallis *H* test for determining the difference between slaughterhouses wastewater characteristics without and with primary treatment and for determining the difference between slaughterhouses wastewater characteristics and slaughterhouses capacity. No significant difference was found between any of the variables.

A good indicator of biodegradability of specific wastewater is ratio BOD_5/COD. If BOD_5/COD is >0.6 then the wastewater is completely biodegradable, and can be effectively treated biologically. If the BOD_5/COD ratio is between 0.3 and 0.6, then the biologically process will be relatively slow (seeding is required). If BOD_5/COD < 0.3, then wastewater cannot be treated biologically because the wastewater generated from these activities inhibits the metabolic activity of bacterial seed due to their toxicity or refractory properties [58]. The relation between BOD_5 and COD for

Table 6
Concentration ranges of selected physico-chemical parameters in raw wastewater (No of samples = 40)

Parameter	Limit	Minimum	Maximum	Mean	St. dev.
COD (mg/L)	450	32.00	4,500.00	977.5416	1,147.3038
BOD_5 (mg/L)	300	3.54	2,871.00	434.3640	632.62802
pH (–)	6.0–9.0	6.01	10.00	7.2442	0.68759
TSS (mg/L)	500	1.00	2,138.00	162.1902	364.95974
FOG (mg/L)	40	0.06	547.60	34.7563	90.54020

Table 7
Corelation matrix between physico-chemical parameters and capacity

	COD (mg/L)	BOD_5 (mg/L)	pH (–)	TSS (mg/L)	FOG (mg/L)
COD (mg/L)	1				
BOD_5 (mg/L)	0.883**	1			
pH (–)	0.004	–0.069	1		
TSS (mg/L)	0.352**	0.353**	–0.138	1	
FOG (mg/L)	0.230*	0.253*	–0.155	–0.020	1

** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).

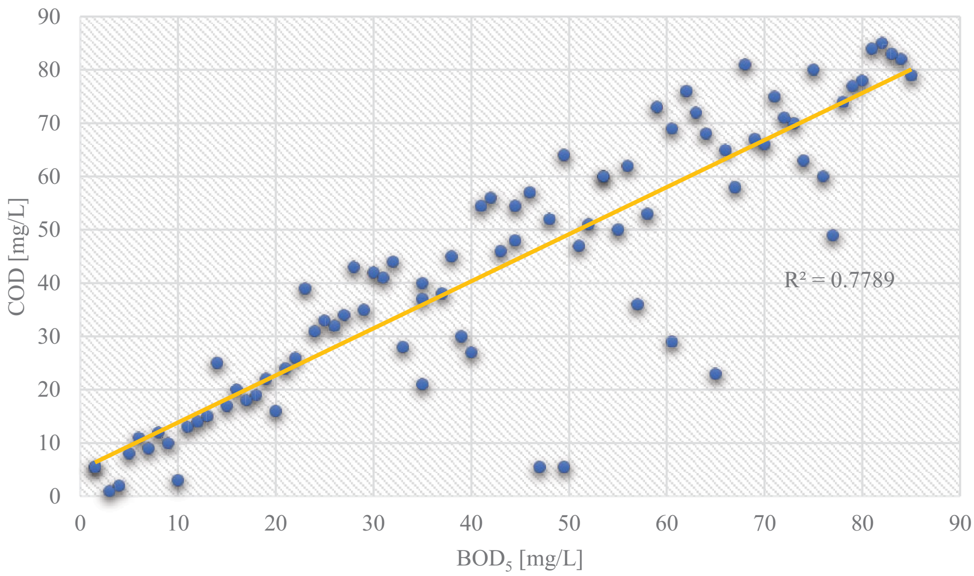

Fig. 13. The visualization of the correlation coefficient matrix of BOD_5 and COD ratio.

different slaughterhouses wastewater in Serbia are presented in Fig. 14. According to the figure, most of the wastewater from slaughterhouses have this ratio between 0.3 and 0.6. For this kind of wastewater, the process of biological treatment would be slow, so it is necessary to use some additional processes to accelerate biodegradation. Wastewater which has a BOD_5/COD ratio under 0.3, cannot be decomposed easily so it is desired chemical or physical treatment. Only two slaughterhouses have BOD_5/COD ratio higher than 0.6 which means that this wastewater can be decomposed completely and biological treatment is feasible.

Based on the results shown, it can be concluded that the concentration of certain pollutants in some situations exceeds the allowed limits up to several times (even in slaughterhouses that have wastewater treatment). All these pollutants have negative effects on the environment. In order to protect the environment, the Republic of Serbia has prescribed a number of legal norms and regulations related to the pollutant emission limits within which wastewater can be discharged from slaughterhouses. On the other hand, the primary thing about these industrial facilities is profit and earnings, and wastewater treatment is currently at the

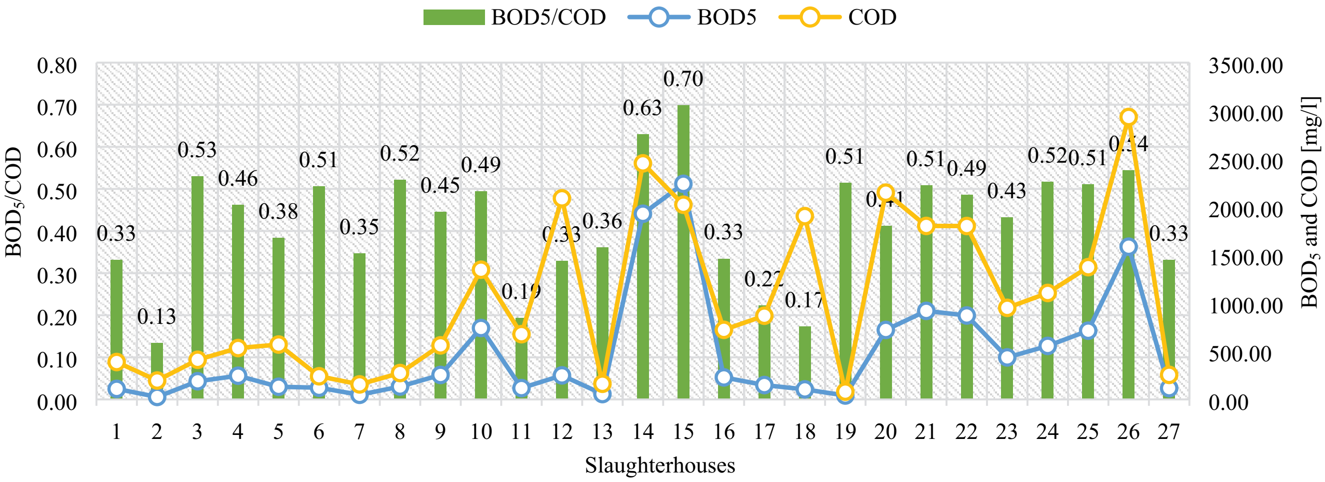

Fig. 14. BOD_5/COD ratio.

bottom of their list of priorities. Based on the results shown, it can be seen that most of these objects do not perform regular sampling and testing of wastewater.

4. Conclusion

During the collection of information, numerous deficiencies and differences in the available data between slaughterhouses were identified. Differences between slaughterhouses come from the fact that prior to the introduction of an integrated permit for the regulation of environmental impact, in this sector, little attention was paid to the monitoring of environmental impacts. This refers especially to FWC by the production process and generation of wastewater in processes.

The slaughterhouse industry is a very sensitive branch of the food industry in terms of wastewater emissions. Despite the fact that there are binding laws that regulate emissions of pollutants, slaughterhouses in the Republic of Serbia do not generally comply with them. Very often, wastewater is discharged without any prior treatment. Even slaughterhouses with some of the wastewater treatment systems installed do not have sufficient measures in place to fulfill the emission limit requirements for wastewater pollutants. Most of the existing wastewater treatment plants in slaughterhouses do not meet the requirements and the already installed plants have been outdated in terms of both, their capacity and the purification technology.

Considering the importance of preserving the natural quality of the environment, as well as completely preventing the pouring of untreated or partially treated wastewater into natural receivers (recipients), it is necessary to consider all possible forms of their treatment and apply the best of them. Solving wastewater problems in slaughterhouses should be addressed according to the phases of the activity. The type and scope of the necessary treatment depend on the precisely defined required quality of the effluent and the efficiency of the applied measures in the production technology. In the treatment of wastewater there is a series of products that can be usefully used.

For future analyses, there is a need to collect more data and information in order to identify and prioritize places where urgent improvements are necessary. There is also a need for monitoring these processes, water consumption, wastewater generation and its characteristics.

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Declaration of interest statement

The authors declare that there is no conflict of interest regarding the publication of this paper.

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