Evaluation of wastewater quality using water quality index

https://doi.org/10.21698/rjeec.2020.213 *Proceedings Paper*

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Abstract
A study for evaluating the quality of wastewater discharged into the sewerage network of Bucharest, for several economic agents with various activity profiles: a car wash, a sweet producer, and a provider of automatic access systems were presented in this paper. The study was conducted over five years (2013-2017). The results obtained for the analyzed parameters were compared with the maximum allowed values (MAV) by the legislation in force. The results showed that for the car wash there was only one exceeding of the chemical oxygen demand (COD) parameter during the whole study period. The sweet producer and the provider of the automatic access systems evacuated wastewater with exceedances of MAV for the parameters: COD, BOD_5, zinc, suspended solids, extractable substances in organic solvents, and total phosphorus. To evaluate the quality of the wastewater discharged by these two agents, the quality indices of wastewater (WWQI) were calculated. For the sweet producer, the calculated water quality indices had values between 62.4 - 92.7%, with a classification of wastewater, discharged in the quality class: marginal to good quality. For the provider of automatic access systems, the value of the quality index was between 74.2 and 85.5, the discharged wastewater being considered fair or good.

Keywords: *wastewater, WWQI, maximum allowed values, Bucharest*

INTRODUCTION

Wastewater is water used in industrial production processes or households, polluted with various substances. The Romanian Water Law defines wastewater as water from domestic, social, or economic activities, containing pollutants or residues that alter its initial physical, chemical, and bacteriological characteristics, as well as rainwater flowing on polluted land.

The variation of the wastewater composition at the entrance to the wastewater treatment plant is very important. Wastewater entering the treatment plant directly influences the operating parameters and its efficiency indicators, consequently, it is necessary for the economic agents to fall within the limits provided by the legislation in force on the quality of discharged water in the city sewerage network, respectively NTPA 002/2005 [1].

Over time, several formulas were developed for the classification of wastewater according to the quality index. The water quality index (WQI) was developed by Horton in 1965 to assess water quality based on the water quality parameters. Since then, several quality water indices have been developed for the assessment of water quality in several areas. These include the National Sanitation Foundation Water Quality Index (NSFWQI), the Canadian Council of Ministers of the Environment Water Quality Index (CCMEWQI), and the Oregon Water Quality Index (OWQI) [2]. For human and environmental safety, the evaluation of water quality is indispensable. The water quality index combines the results of several water quality parameters resulting in a dimensionless number that provides information on water quality [3]. Most water quality indices were used for the general assessment of water quality, while other indices targeted specific uses such as drinking water supply [4, 5] or irrigation [6]. The wastewater quality discharged by different economic agents can be compared by the values of WQI [7, 8]. Results can be used to help the authorities to identify sources of pollution and to take appropriate actions for future improvements [9-11].

The paper presents the study for evaluating the quality of wastewater discharged into the sewerage network of Bucharest for three economic agents with various activity profiles:

a car wash, a sweets producer, and a provider of automatic access systems. The study was carried out over five years (2013-2017), and the parameters analyzed for the characterization of wastewater quality were following legislation.

EXPERIMENTAL PART

Sampling

The wastewater samples were collected from the following economical agents:
- car wash unit: one sampling point, wastewater resulting after washing cars (C1);
- sweets producer factory: three sampling points, such as R1 and R3 (technological wastewater), R2 (domestic wastewater);
- a provider of automatic access systems factory: wastewater from 3 sampling points, A1 connecting pipe that discharges technological wastewater, A2 connecting pipe that evacuate domestic wastewater, and A3 connecting pipe that evacuates meteoric wastewater.

The monitoring of the wastewater discharged by these companies was performed monthly. Maximum admissible values according to the legislation in force are given in Table 1.

Table 1. Maximum admissible values according to NTPA-002 Quality Norm

Parameter	Measurement unit	Maximum admissible value (MAV)*
pH	pH units	6.5-8.5
Suspended solids (SS)	mg/L	350
Chemical oxygen demand (COD)	mgO_2/L	500
Biochemical oxygen demand (BOD_5)	mgO_2/L	300
Ammonium	mg/L	30
Total phosphorus	mg/L	5
Sulfates	mg/L	600
Extractable substances in organic solvents	mg/L	30
Anionic surfactants	mg/L	25
Free residual chlorine	mg/L	0.5
Zinc	mg/L	1

*NTPA 002/05 - Normative regarding the wastewater discharge conditions in the sewerage networks of the localities and directly in the treatment plants, according to HG 352/2005.

Wastewater quality index

To assess the quality of wastewater several water quality indexes were developed [12].
The WWQI-wastewater quality index is a mathematical expression of the Canadian Council of Environment Ministers (CCMEWWQI).

$$WWQI = 100 - \frac{\sqrt{F_1^2+F_2^2+F_3^2}}{1{,}732} \quad (1)$$

where *F1* - number of determined quality indicators, whose values exceed the maximum limit allowed by legislation x 100 / total number of monitored quality indicators, *F2* - number of determined quality indicators, whose values exceed the maximum limit allowed by legislation x 100/ total number of tests, *F3* - nse/0.01nse+0.01, *nse* - the sum of all individual deviations/total number of tests (∑E/ total tests), *E* - deviation (the number of tests whose values exceed the reference value/reference value)-1.

$$CCMEWWQI=100-WWQI \quad (2)$$

Table 2 shows the water quality class function of the values of the water quality index of the Canadian Council of Environment Ministers.

Table 2. Water quality class depending on CCMEWWQI values

Quality Class	CCMEWWQI Value	Description
Excellent	95-100	All measurements are within objectives virtually all of the time
Good	80-94	Conditions rarely depart from natural or desirable levels
Fair	65-79	Conditions sometimes depart from natural or desirable levels
Marginal	45-64	Conditions often depart from natural or desirable levels
Poor	0-44	Conditions usually depart from natural or desirable level

RESULTS AND DISCUSSION

Results obtained for wastewater quality discharged by the car wash economic agent

For the car wash economical agent, the results obtained for the parameters determined in the wastewater sample, analyzed in the period 2013-2017, falls within the imposed limits by NTPA 002, except COD, in May 2017.

From Figure 1, where the COD concentrations were graphically represented, it can be observed that the values obtained for this indicator were below the maximum allowed value (MAV) from NTPA 002 (500 mg O_2/L). The exception was in May 2017, when the value obtained was 547.2, the result being above the maximum allowed concentration.

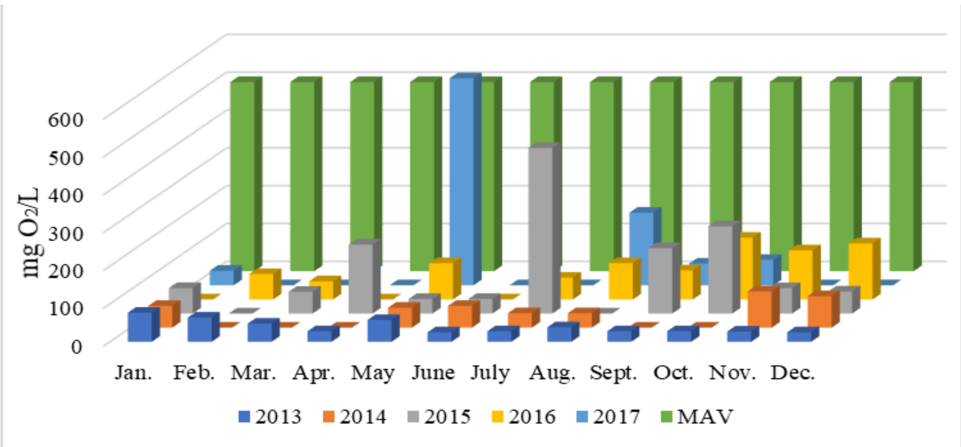

Fig. 1. COD content in C1 wastewater

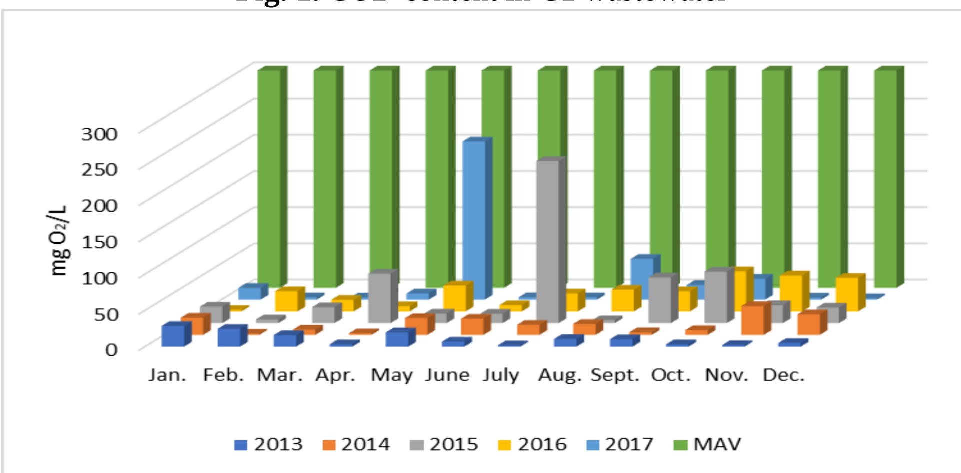

Fig. 2. BOD_5 content in C1 wastewater

BOD_5 values obtained were within the maximum admissible values imposed by NTPA 002 (300 mg O_2/L) with the highest value obtained in May 2017 (218.3 mgO_2/L) (Fig. 2).
Although car wash economical agents use anionic surfactants daily, the concentration of anionic surfactants discharged in the period 2013-2017 was within the maximum limits allowed by NTPA 002 (25 mg/L), the results obtained being in the range of 0.05-3.2 mg/L (Fig. 3).

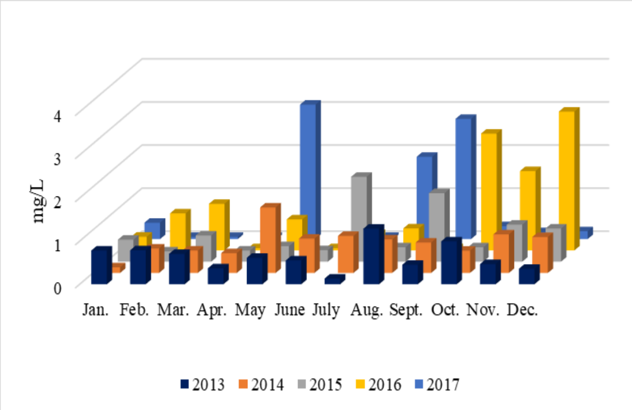

Fig. 3. Anionic surfactants content in C1 wastewater

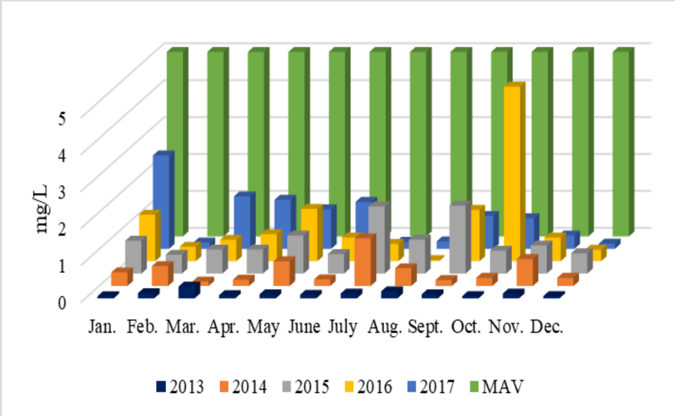

Fig. 4. Phosphorus content in C1 wastewater

Regarding phosphorus, it had values below the maximum admissible limit imposed by NTPA 002 (5 mg/L), the highest value obtained during the study being in October 2016 (4.76 mg/L), a value close to the allowed limit (Fig. 4).
At the car wash unit were not recorded exceeding of the analyzed parameters. For this reason, the quality indices were not calculated.

Results obtained for wastewater quality discharged by the sweets producer

The second economic agent from this study was a producer of different types of sweets (chocolate, biscuits, pastries). The parameters studied were those indicated in Table 1, except zinc.
For R1, the results obtained showed that in 2013 the parameters ammonium, sulfate, and anionic surfactants were below the maximum value allowed by NTPA 002.
In next figures are presented the results for the indicators that exceed the maximum concentrations admitted by NTPA 002: COD, BOD_5, suspended solids, total phosphorus, extractable substances in organic solvents, and pH.
Figure 5 shows that the COD parameter determined in the period 2013-2017 in R1 exceeded the maximum allowed the limit (500 mgO_2/L) in 2013 (January, June, and August) and 2014 (June to September). In the period 2015-2017, the COD indicator falls within the maximum allowed limit due to the improvement of the technological process.
Figure 6 shows an exceedance of the biochemical oxygen content in R1 in June and August 2013 and in June, July, and September 2014.

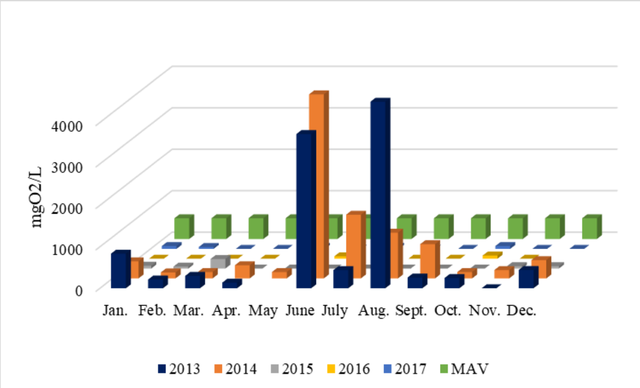

Fig. 5. COD content for R1 wastewater

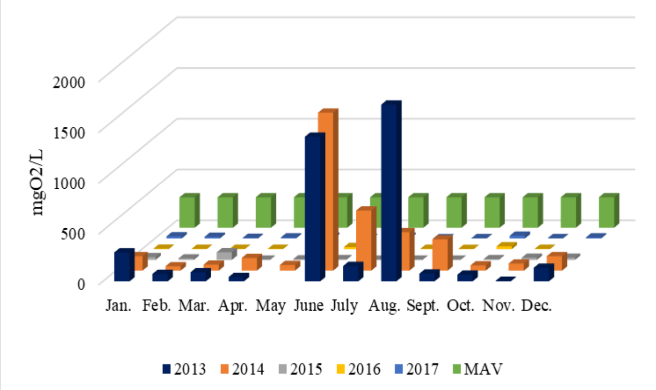

Fig. 6. BOD_5 content in R1 wastewater

Figure 7 shows the content of suspended solids in connection R1, where there was a single exceedance throughout the study (July 2013), the recorded value being 1800 mg/L.
For the total phosphorous parameter, MAV was exceeded in 2014 (May, June, July, and September) and in 2015 (February and March) (Fig. 8).
For the extractable substances in organic solvents, MAV was exceeded in 2013 (May, July) and in 2014 (July) (Fig. 9).

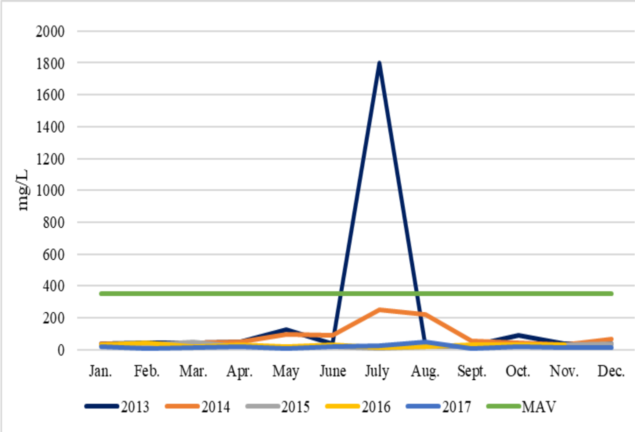

Fig. 7. Suspended solids content in R1 wastewater

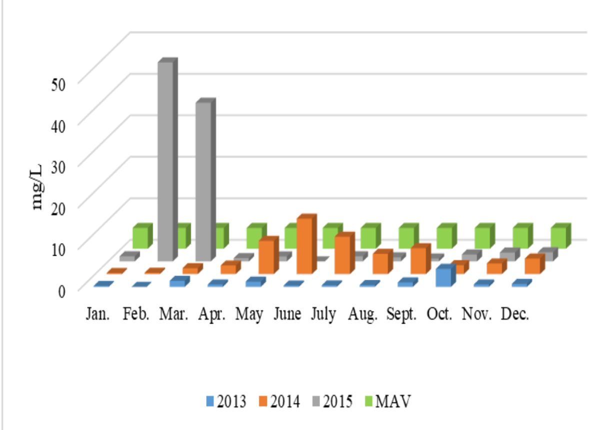

Fig. 8. Total phosphorus content in R1 wastewater

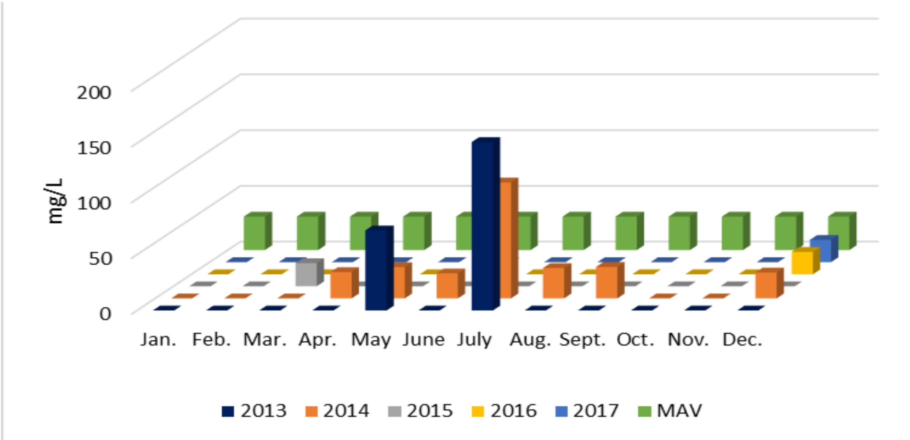

Fig. 9. The extractable substances in organic solvents in R1 wastewater

The pH in R1 had values in the range allowed by NTPA 002, with small exceptions in January, May 2013, and July 2014, when acidic pH values were recorded (value under the minimum acceptable value: 6.5 pH units) (Fig. 10).

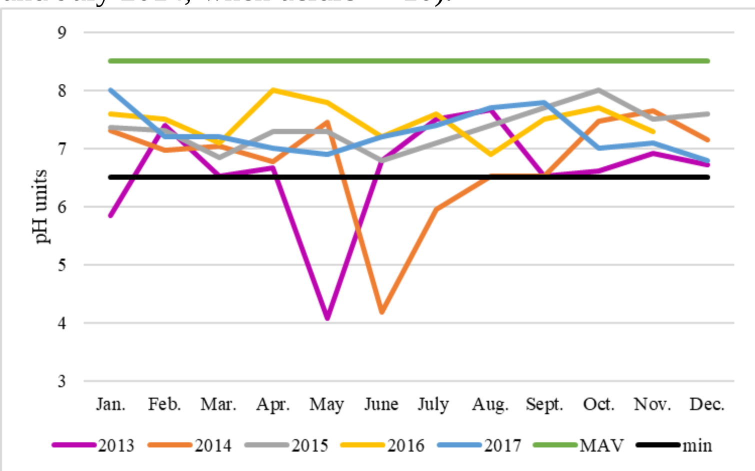

Fig. 10. pH value in R1 wastewater

From the results obtained, it can be observed that the month with the most exceedances in 2014 was July, where five determined parameters had values over the maximum allowed concentration.

In 2015, there were exceedances in only two samples (February and March) for the total phosphorus parameter and in 2016 and 2017, none of the parameters analyzed for R1 had values above the limits imposed by NTPA 002.

In R2, where domestic wastewater is discharged, there was only one overrun for the phosphorus parameter in July 2014.

In R3 as well as in R1, where the wastewater resulting from the technological processes is discharged, there were several exceedances of the analyzed parameters: COD, BOD_5, total phosphorus, extractable substances in organic solvents, and pH. The parameters ammoniacal nitrogen, suspended solids, sulfate, and anionic surfactants were below the maximum value allowed by NTPA 002.

Figure 11 shows the chemical oxygen demand determined from the technological wastewater from the R3 connecting pipe. There are several exceedances of MAV in 2014 (in 50% of the samples), compared with 2016 and 2017 when only two exceedances, respectively one exceedance of the COD value were recorded.

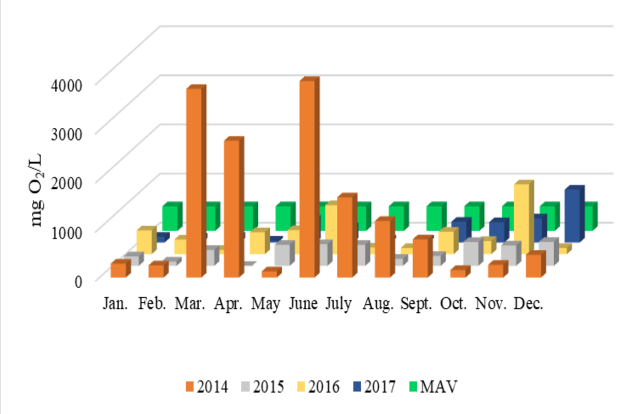

Fig. 11. COD content for R3 wastewater

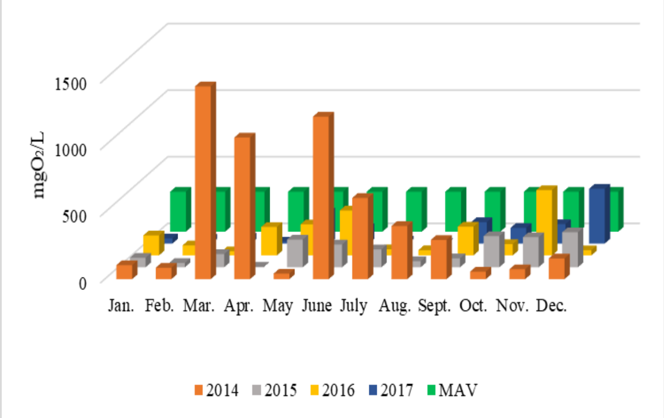

Fig. 12. BOD_5 content for R3 wastewater

Figure 12 shows the exceeding of the maximum concentration of BOD_5 in R3 in 2014 (March, April, June, July, August), in 2016 (November), and in 2017 (December).

For the total phosphorous parameter, MAV was exceeded in 2014 (June and July). In 2015, February, and March, the MAV for the total phosphorus parameter was also exceeded, a situation similar to that of R1, in the same year (Fig. 13).

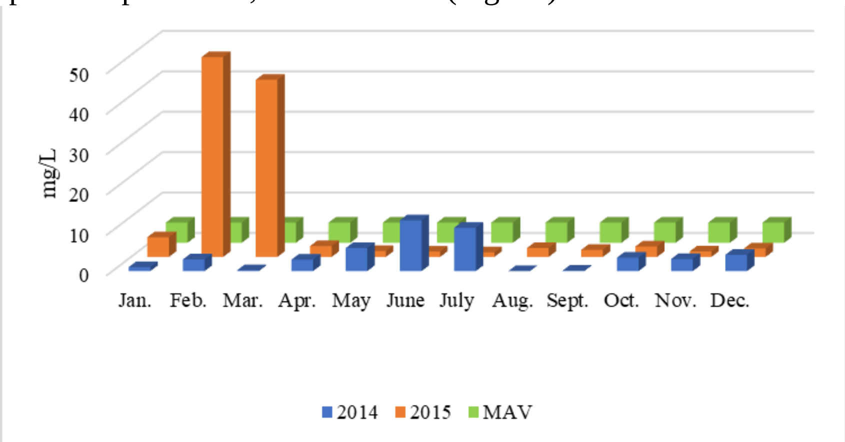

Fig. 13. Total phosphorus content in R3 wastewater

For the extractable substances in organic solvents, MAV was exceeded only in 2014 (March, April, July, August, and September). The highest value for the extractable substances in organic solvents in July was 4.5 times higher than MAV (Fig. 14).

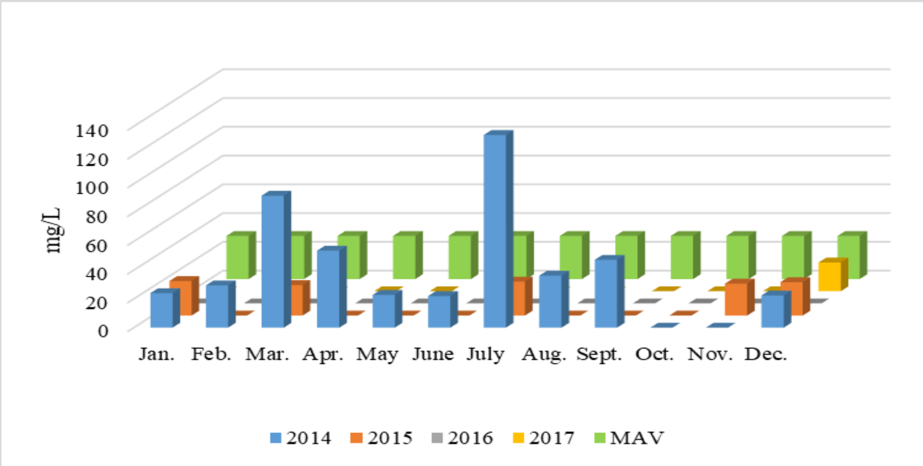

Fig. 14. The extractable substances in organic solvents content in R3 wastewater

The pH in R3 had values under the minimum acceptable value: in 2014 (April, July) and 2016 (November) (Fig. 15).

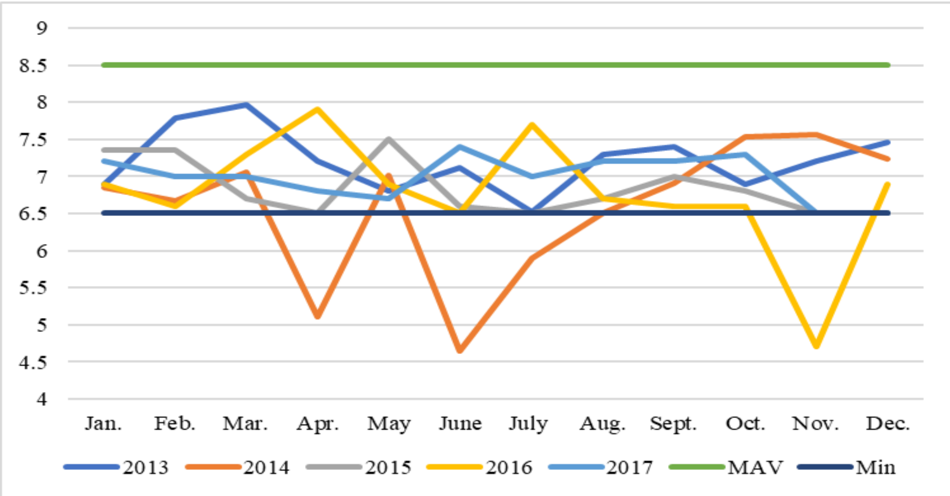

Fig. 15. pH values in R3 wastewater

For the candy producer, the wastewater quality indices for the connecting pipes R1 (2013, 2014, and 2015), R2 (2014), and R3 (2014-2017) were calculated because only in these periods there were exceedances of the maximum allowed values for the parameters: COD, BOD_5, suspended solids, extractable substances in organic solvents, total phosphorus, and pH. The results obtained are shown in Table 3.

Table 3. The quality indices values and the quality class for R1, R2 and R3

Sampling point	Year	CCMEWWQI	Quality Class
R1	2013	76.78	Fair
R1	2014	68.82	Fair
R1	2015	87.30	Good
R2	2014	92.71	Good
R3	2014	62.40	Marginal
R3	2015	88.64	Good
R3	2016	70.85	Fair
R3	2017	76.78	Fair

From the results obtained for wastewater quality indices (Table 3) it was observed that in the R1 connecting pipe, the wastewater evacuated had a fair quality in 2013 and 2014.

This value for the quality index (CCMEWWQI) is explained by the fact that, in 2013, the COD, BOD_5, suspended solids, extractable substances in organic solvents were exceeding the MAV values. In 2014 the COD, BOD_5, extractable substances in organic solvents, and total phosphorus parameters were recorded exceeding MAV. In 2015 there was an improvement of wastewater quality, the wastewater was included in a good quality class. In 2016 and 2017 there were no overruns for any parameter determined in this sampling point, which means an improvement of the technological processes used.
For the R2 sampling point, only in 2014 one parameter exceeded the MAV. Despite this fact, WWQI indicates the good quality of the wastewater.
The wastewater discharged through the R3 connecting pipe has obtained the worst classification in 2014: marginal. That was because the COD and BOD_5 values were exceeded in six different months during the year. The value of extractable substances in organic solvents had four values above the maximum allowed limit and the pH and phosphorus had an exceedance of the limits imposed by NTPA 002 in two of the 12 months of 2014. These excesses are due to the use of fats (butter, margarine), in the production of sweets. In the following years, there was an improvement in technology, the water quality being good (in 2015), and acceptable (2016, 2017).

Results obtained for wastewater quality discharged by the automatic access systems company

The third economic agent studied was the provider of automatic access systems. The study included data obtained from the physical-chemical analyses of technological wastewater from the manufacture of hardware (safety cylinders, safes, padlocks, cards and readers, locks, alarms, electromagnets, security doors).
The results obtained for most of the parameters determined in the technological wastewater from the A1 sampling point fall within the maximum allowed limits imposed by NTPA 002. Exceedances of the allowed values for COD, BOD_5, Zn, and a strongly acidic pH (0.8 pH units) were recorded only in August 2016 when a hydrochloric acid cleaning took place. Generally, the COD values were situated between 30÷40 mgO_2/L but in August 2016 the value was 5400 mgO_2/L exceeding 11 times MAV. For BOD_5 values were between 2÷11 mgO_2/L but in August 2016 the value was 2031 mgO_2/L, exceeding 4 times MAV. Zinc registered values were between 0.01÷13.1 mgO_2/L (figure 16). Exceedances for Zn were also recorded in August and September with a maximum value exceeding 13 times MAV, in November 2016.

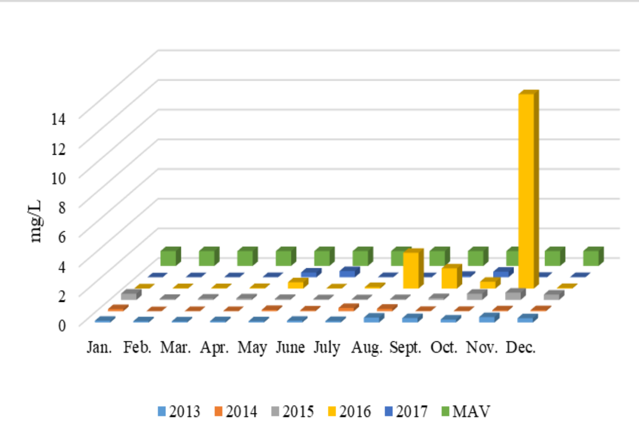

Fig. 16. Zn value in A1 wastewater

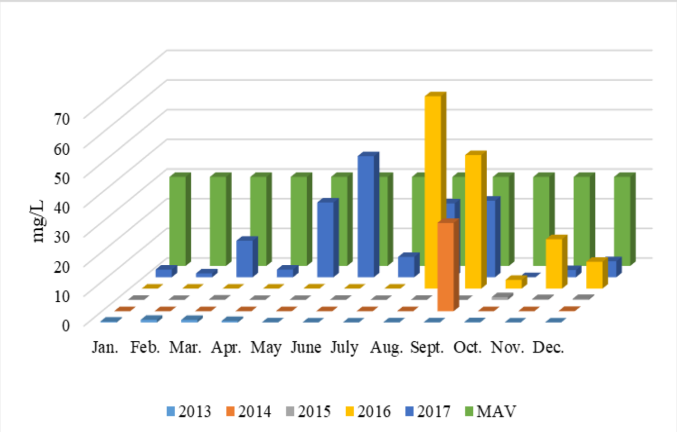

Fig. 17. Ammonium value in A2 wastewater

Also in November 2016, the pH was acidic (6.0 pH units), under the minimum acceptable value. Ammonium was under MAV the whole period of the study with values between 0.1÷5 mg/L. Also, the total phosphorus had values below MAV, between 0.1÷1 mg/L.
In the period 2013-2015 most results of the indicators determined from the A2 (domestic wastewater) sampling point were situated under the maximum concentrations admitted by

NTPA 002. COD values were under MAV, between 30÷415 mgO_2/L, except August 2016 when MAV was two times exceeded. Like COD, BOD_5 had values below MAV, with values between 1.6÷113 mgO_2/L except August 2016 when BOD_5 was 348 mgO_2/L, and MAV was exceeded.
Ammonium was exceeded in August and September 2016 and in June 2017 (Fig. 17). The maximum value recorded in August 2016 exceeded twice the MAV.
The total phosphorus content discharged from the domestic water through the A2 sampling point registered a single exceedance in June 2017 (Fig. 18).

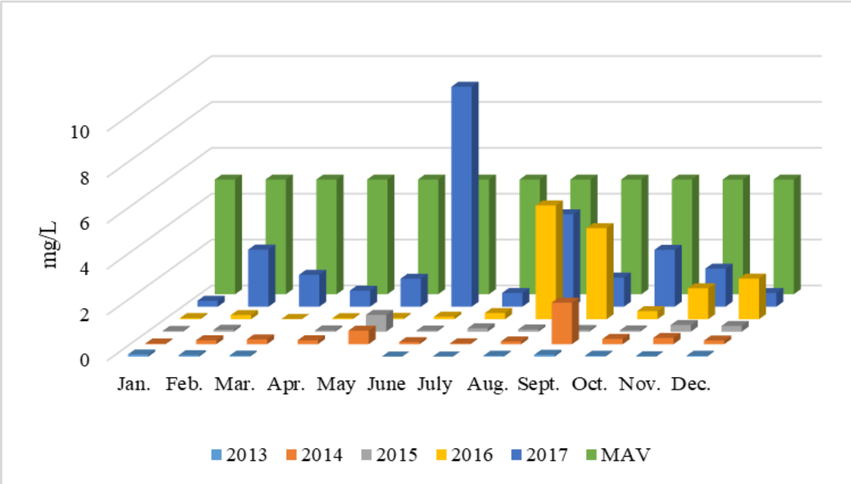

Fig. 18. Total phosphorus value in A2 wastewater

The results obtained for all the determined parameters of the A3 (meteoric wastewater) were within the allowed limits of NTPA 002 for the entire studied period, of five years.
The wastewater quality indices were calculated for the years in which exceedances were registered (A1 and A2 in 2016 and A2 in 2017). The results for the quality index are presented in Table 4.

Table 4. The quality index and quality class values for A1 and A2

Sampling point	Year	CCMEWWQI	Quality Class
A1	2016	74.17	Fair
A2	2016	78.16	Fair
A2	2017	85.50	Good

The values of CCMEWWQI were situated into the fair quality class in 2016, for A1 and A2 sampling points. A1 had 4 indicators (7 samples) whose value exceeded the MAV: COD (in one sample), BOD_5 (in one sample), zinc (in 3 samples), pH (in 2 samples). In the A2 sampling point, the MAV exceeded 3 indicators (4 samples): COD and BOD_5 one sample each, and in the case of ammonium 2 samples had values above the MAV. In 2017, A2 had values above MAV only for 2 indicators (2 samples): ammonium and total phosphorus, the quality class obtained being a good one.

CONCLUSIONS

In this paper, the quality of the wastewater discharged in the water sewerage network from Bucharest by three economical agents with a different profile of activity, was studied. The results of the physical-chemical investigation performed during the period 2013-2017 were used for calculation of the wastewater quality indices. WWQI represents a simple and rapid tool for an indication of wastewater level of pollution and at the same time, offers useful information for improving or developing the wastewater treatment processes.

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