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Pollution parameters and identification of performance indicators for wastewater treatment plant of Medea (Algeria)

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ABSTRACT

The sanitation system in Algeria requires a mastery of the functioning of the collection network and treatment using performance indicators that identify gaps and to develop solutions for better wastewater management. This work aims to identify the performance indicators that are chosen on the basis of the problems often encountered. The referred performances concern the problems related to clear parasites waters and some that highlight the phenomena of sedimentation–erosion in the network of Medea city. For the WWTP, we are interested in the plant hydraulic and treatment capacity, the bacterial metabolism, the treatment yield, the correlations between pollution parameters and the energy consumption. The results showed that the dilution rate of wastewater, which is caused by the clear parasites waters, requires significant care at the sewerage network. The imbalance into nutrients relating to bacterial metabolism can be an obstacle at the level of biological treatment. For high ratios TSS/COD and TSS/BOD$_5$ that translate a pollution at particulate character, a quantitative study would be required in particular to evaluate the influence of collection networks on the quality of domestic sewage. The high values of the electrical energy necessary for the elimination of recorded pollution require to perform a diagnostic analysis on the installation.

Keywords: Sanitation network; Treatment plant; Performance indicators; Ratios; Optimization; Medea

1. Introduction

Despite the magnitude of the spin-offs, which are generated by wastewater on the degradation of the environmental medium, on water scarcity and consequently on public health, according to [1], in Algeria, little importance is given to sanitation services compared with drinking water ones. The sanitation problems remain a major concern that requires significant care by taking appropriate measures to protect the environment [2]. According to [3], the management of sanitation systems has to face several facts such as

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physical degradation of infrastructure due to its aging, lack of maintenance and pollution of natural environments by increasingly disturbing direct and indirect discharges from urban sanitation.

The nature of our networks, their designs and urban extensions have increased the flood risk making our sanitation networks insufficient and unable to follow urbanization. Moreover, the overall volume of treated water according to [4] represents only 19% of the collected volume of wastewater.

This situation inquires more research to improve performances by locating the failures in sanitation system through research of performance indicators that can be used to analyze the sustainability of sanitation service. The establishment of these performance indicators therefore constitutes an assistance tool at the enhanced management of treatment plants and sewage collection systems.

In this context of sanitation system control, we sought to obtain and valorize the maximum available data concerning hydraulics and monitoring of the main physico-chemical pollution parameters. The results should detect gaps and propose technical solutions for better management and improvement of the evacuation and treatment yield of sewage facilities of Medea city.

2. Materials and methods

Implemented and commissioned in April 2007, the wastewater treatment plant (WWTP) is located in the south of the Medea city; it is designed to treat wastewater of this city and its surroundings. This wastewater flows by gravity to the station (Fig. 1) by a single collector as the sewerage

system is unitary. It operates with low mass load according to an extended aeration process [5].

This plant treats the resulting pollution of an equivalent population of 162,500. The sanitation network is of a total linear of 243.19 Km, with a connection rate of 99%. The city sewage system is divided into two parts northern and southern, and only the southern part is connected to the WWTP. The daily wastewater volume arriving to the WWTP is 10,723 m^3/d that represents 41% of the nominal capacity of the WWTP that is 26,000 m^3/d.

The treatment system comprises successively the following operations: pre-treatment, biological treatment, a chlorine station, thickening, then sludge drying [5].

In the framework of this work, we have proceeded to the control and monitoring of various measured and analyzed parameters of the raw and treated water of Medea city WWTP, during the period January 2013–November 2015.

The water analyses were made at the laboratory of WWTP. The different measured parameters, the used methods and equipment are given in Table 1.

3. Experimental results and interpretations

3.1. Evolution of the hydraulic load and share of clear parasitic waters

The treatment plant of Medea was designed for a nominal flow of 26,000 m^3/d. The overruns of recorded flows are given in the Table 2.

The excess in flow represents the share of clear parasites waters (CPW) that have increased significantly during the
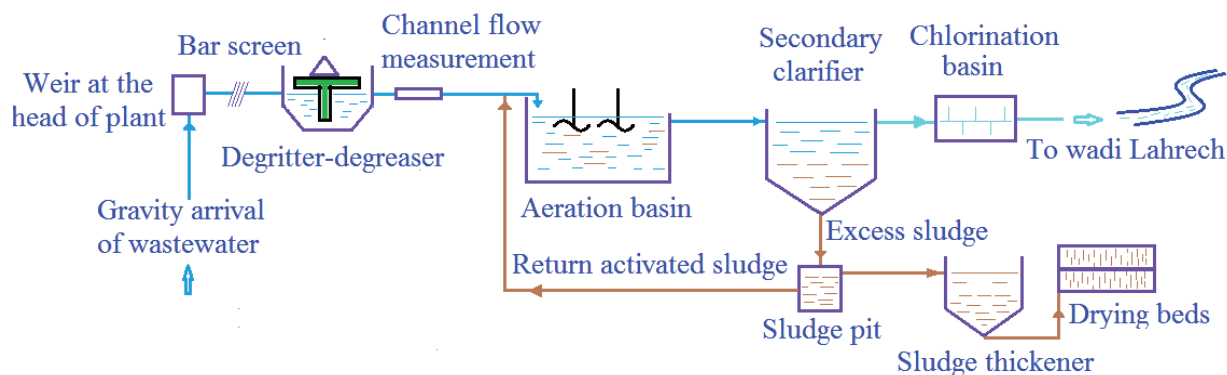

Fig. 1. Schematic representation of the WWTP of Medea.

Table 1
Material and analytical methods

Parameter	Analysis method	Material used
Total suspended solids (TSS)	Filtration–centrifugation	Centrifuge Hermle Z300 – oven at 105°C
COD	Oxidation by $K_2Cr_2O_7$	Heating block Brand Behr Labor Technik
BOD_5	Respirometric	Flasks OxiTop IS12, WTW-Enclosure 20°C
TKN	Kjeldahl	Digester-distiller/Buchi
NH_4^+	Spectrometric ISO 7150-1	Spectrophotometer HACH DR/4000 V
NO_3^-	Spectrometric ISO 7890-3	Spectrophotometer HACH DR/4000 V
PO_4^{3-}	Spectrometric ISO 6878	Spectrophotometer HACH DR/4000 V

rainy season (September, October and December). According to [6], the CPW (drainage water, fountains, cooling, etc.) also overload unnecessarily the network collectors. They dilute the wastewater before treatment. They can cause the increase of upstream rejection into the network, involving an increase in operating costs of WWTP and preventing the achievement of required performance.

The average flow is 51% of the nominal capacity (Fig. 2), but we met a flow excess for some days in September, October and December 2013. As long as the nominal capacity is not

reached, such peak loads should be absorbed by the WWTP without any problem.

The share of CPW is calculated by evaluating the effect of dilution of wastewater by clear waters on the BOD_5 parameter compared with theoretical undiluted wastewater [6] with an inhabitant equivalent (IE) corresponding to a daily pollution load of 60 g of BOD_5 and 150 l/d of consumed water [7].

We proceed as follows (see Table 3):

Raw water is designated by (1); incoming load in kg BOD_5/d, designated by (2); incoming load in IE, designated by (3); theoretical undiluted wastewater volume, designated by (4); CPW volume designated by (5); and dilution rate designated by (6).

We will have:

$$(3) = (2) \times 1{,}000/60$$

$$(4) = (3) \times 150/1{,}000 = (2) \times (1{,}000/60) \times (150/1{,}000) = (2) \times 150/60 = (2) \times 2.5$$

$$(5) = (1) - (4) = (1) - 2.5\,(2)$$

Hence, we shall have an equation of the form as follows:

$$Y = a - bX$$

where Y is the daily volume of CPW; a is the daily volume of wastewater; $b = 150/60 = 2.5$; and X is the incoming load in kg BOD_5/d.

We note a generally higher rate of dilution during the rainy events.

The CPW volume is estimated from BOD_5 concentrations at the inlet of WWTP. The CPW (BOD_5) is given by the

Table 2
Maximum flows recorded

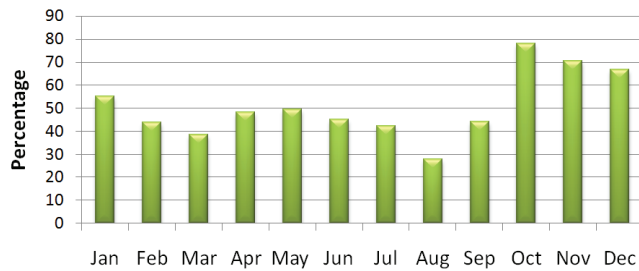| Period	Flow max (m³/d)	Overruns/nominal flow, % (26,000 m³/d)
September 2013	26,280	1.1
October 2013	33,540	29
December 2013	27,000	3.84

Fig. 2. Report of the flow relative to the nominal capacity – 2013.

Table 3
Calculation and evolution of the dilution rate

Date	Raw water, m³/d (1)	Incoming load, Kg BOD_5/d (2)	Incoming load (IE) 1IE = 60 g BOD_5/d (3)	Theoretical undiluted wastewater, m³/d With 150l/IE/d (4)	Clear parasite water, m³/d (5)	Dilution rate, % (6)
Jan. 6, 2015	13,380	4,282	71,360	10,704	2,676	25
Feb. 10, 2015	17,250	3,795	63,250	9,488	7,763	82
Feb. 18, 2015	16,400	3,280	54,667	8,200	8,200	100
Mar. 8, 2015	10,240	2,355	39,253	5,888	4,352	74
Apr. 1, 2015	5,360	1,179	19,653	2,948	2,412	82
May 25, 2015	10,540	2,108	35,133	5,270	5,270	100
June 21, 2015	8,750	1,838	30,625	4,594	4,156	90
July 19, 2015	4,350	348	5,800	870	3,480	400
July 21, 2015	5,240	603	10,043	1,507	3,734	248
July 28, 2015	7,380	886	14,760	2,214	5,166	233
Sep. 8, 2015	6,810	953	15,890	2,384	4,427	186
Sep. 14, 2015	6,090	1,035	17,255	2,588	3,502	135
Sep. 16, 2015	6,800	476	7,933	1,190	5,610	471
Sep. 21, 2015	7,520	1,429	23,813	3,572	3,948	111
Oct. 13, 2015	11,520	2,189	36,480	5,472	6,048	111
Nov. 2, 2015	11,480	2,640	44,007	6,601	4,879	74

equation of the form $Y = a - bX$, which confirms that less lower measured concentrations are, the more important the share of CPW is.

The estimate of the average share of CWP for the study period from January 2013 to November 2015, with a daily average volume of 10,723 m³/d and an BOD_5 average concentration of 352.33 mg/l, leading to an average daily load BOD_5 of 3,778 kg/d, is estimated from the equation $Y = a - bX$. Therefore, we will have $Y = 10,723 - 2.5 \times 3,778 = 1,278$ m³/d, representing 14% of the volume of the theoretical undiluted wastewater found of 9,445 m³/d.

3.2. Treatment performance obtained

3.2.1. Monitoring of nitrogen treatment (see Table 4)

Total Kjeldahl nitrogen (TKN) is the most representative parameter of the wastewater collection [8]. The average concentrations of Kjeldahl nitrogen at the inlet and outlet WWTP are, respectively, 55.5 and 5.20 mg/l; therefore, the abatement is 91%.

The average concentrations of ammonia NH_4–N varies from 29.36 to 3.46 mg/l from the inlet to the outlet. However, the nitrate concentrations NO_3–N at the inlet vary between 0.01 and 2.25 mg/l with an average of 0.59 mg/l. Their contents at the outlet vary between 0.02 and 27.11 mg/l with an average of 10.61 mg/l. Therefore, an increase of 1,698%, from the inlet to the outlet, which is due to nitrification.

We can consider that the nitrification only works well if the concentration of ammonia nitrogen in the treated water is less than 1 mg NH_4–N/l, conversely, if the concentration of nitrate nitrogen in the treated water exceeds, in dry weather, 3–5 mg NO_3–N/l [9]. The increase in the daily duration of aeration helps to speed up the restoration of good nitrogen processing performance, but it is not imperative for the viability of nitrification [10]. For the Medea WWTP, it is necessary to reduce the daily duration of aeration.

3.2.2. Monitoring of phosphorus treatment

At the intake to the WWTP, phosphates oscillate between 0.73 and 7.85 mg/l with an average of 2.29 mg/l. At the outlet, the average residual content of orthophosphate is 0.63 mg/l.

These values are very high compared with the tolerable limit of 0.1 mg/l total phosphorus for the discharge of effluent into a sensitive medium at eutrophication [11]. However, they are lower than 10 mg/l; in ortho-phosphates, this limit being acceptable for a direct discharge into the receiving environment [12]. The level of phosphorus elimination is unstable and weak with an elimination average yield of 72%.

3.2.3. Nutritional balance

The bacterial metabolism is accompanied by nitrogen needs in the form of ammoniacal nitrogen, and phosphorus needs in the form of orthophosphates, in the following proportions BOD_5/NH_4–N/PO_4–P: 100/5/1 [13].

For an average BOD_5 of 352.33 mg/l (see Table 5) and for respecting that theoretical ratio, the concentrations of NH_4–N and PO_4–P must be, respectively, 17.61 and 3.52 mg/l. However, the average values recorded (29.36 mg/l NH_4–N and 2.29 mg/l PO_4–P) indicate a deficit of 35% for PO_4–P and an increase of 67% for NH_4–N relative to the respective theoretical ratios. This imbalance in nutrients can constitute a handicap at the level of biological treatment.

3.2.4. Monitoring of organic loads treatment (see Table 5)

The TSS represents 109% of the nominal value (Fig. 3), with a frequency of excess of 63% and an abatement yield of 95.35%.

The BOD_5 is equal to 104% of the nominal value (Fig. 3) and records an exceedance frequency of 62% and a 96.31% removal efficiency.
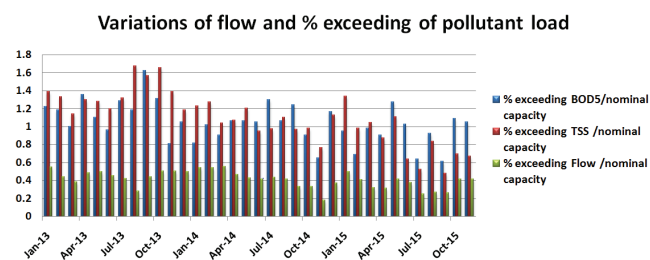
Variations of flow and % exceeding of pollutant load

Fig. 3. Variations of flow and % exceeding of BOD_5 and TSS relative to the nominal capacity.

Table 4
Results of the nitrogen from inlet to the outlet of the WWTP (Jan. 2013–Nov. 2015)

Parameters	Average		Max.		Min.	
	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet
TKN mg/l	55.5	5.20	75	11	37	3.70
NH_4–N mg/l	29.36	3.46	47.20	26.96	6.90	0.03
NO_3–N mg/l	0.59	10.61	2.25	27.11	0.01	0.02

Table 5
Results of global parameters of raw and treated wastewater (Jan. 2013–Nov. 2015)

Parameters	Average		Max.		Min.		Nominal value
	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	
TSS mg/l	479.44	22.31	733.71	175.11	211	6.57	438
COD mg/l	624.97	55.10	846.16	290	351.09	31.20	675
BOD_5 mg/l	352.33	13	548.67	150	206.25	2.67	338

The COD yield removal is 91%. This is a sharp reduction of the COD, which according to [14] is related to a better oxygenation that enables aerobic bacteria to proliferate and to assure accordingly, better mineralization or oxidation of the organic matter. The maximum value (846.16 mg/l) is increasing by 35% compared with the average concentration (624.97 mg/l).

In 2015, the annual average load of BOD_5 at the inlet of WWTP is 971 tons and represents 71% of the annual average load recorded in 2014 (1,371 tons). But at the outlet, the load flow discharged into the watercourse during 2015 is 32 tons of BOD_5, representing 50% of the load dismissed in 2014, which was 64 tons. The BOD_5 load decrease from 71% to 50% from the inlet to the outlet of the year 2015 compared with 2014, because of the removal efficiency of 96.18% in 2015, which increased by 1.65% relative to 94.38% recorded in 2014.

3.2.5. Ratios

The use of these characterization parameters is a good means to give a picture of the raw effluent pollution degree and also to optimize the physico-chemical parameters of the wastewater in order to propose a suitable mode of treatment. The values of different ratios are given in Table 6.

COD/BOD_5 (raw water): The biodegradability coefficient is calculated by the ratio COD/BOD_5 and depends on the nature and origin of the wastewater, which may be domestic or industrial, and requires different treatments according to [15]. The ratio COD/BOD_5 for raw wastewater is generally between 1.25 and 2.5. When the ratio COD/BOD_5 is between 3 and 7, wastewater can be hardly biodegradable. This ratio was found of 1.77, which is characteristic of a domestic effluent. A value less than 2 confirms the biodegradability of the wastewater. Therefore, the biological treatment is adequate for these effluents.

COD/BOD_5 (treated water), found 4.24, shows a decrease in the share of oxidizable organic matter during the treatment process.

BOD_5/COD: This ratio gives very interesting indication about the origin of pollution and its treatment possibilities [16]. The report BOD_5/COD of 0.56 is higher than 0.40 found

Table 6
Relation between the pollution parameters

RATIO	Average	Max.	Min.
TSS/BOD_5	1.36	2.22	0.8
COD/TSS	1.3	2.07	0.87
TSS/COD	0.77	1.15	0.48
COD/BOD_5 (raw water)	1.77	2.25	1.52
COD/BOD_5 (treated water)	4.24	14.4	1.63
BOD_5/COD	0.56	0.66	0.44
BOD_5/TKN	6.34	9.89	3.72
BOD_5/TSS	0.73	1.24	0.45
NH_4/TKN	0.53	0.85	0.12
TKN/BOD_5	0.16	0.27	0.10
COD/TKN	11.26	15.25	6.33
NH_4/COD	0.05	0.08	0.01

by [16]. Therefore, here again this effluent is biodegradable and confirms that these waters are loaded with organic matter (56%) and inorganic matter (44%). According to [17], this organic load makes this wastewater rather unstable, i.e., it quickly evolves toward "digested" forms with the risk of odors release.

COD/TKN: Equal to 11.26 and according to [18], for a strict urban effluent, this ratio is between 8.8 and 12, and indicates the mixity of the effluent and has an influence on the denitrification. In the case of a wastewater with a low COD/TKN ratio, organic carbon content of the digested effluent may be insufficient to achieve complete denitrification [19]. But too high COD/TKN ratios risk also to disturb the nitrification because COD/TKN has a direct effect on the autotrophic biomass concentration of sludge and thus on the maximum speed of nitrification [10].

NH_4/TKN: This ratio will indicate the degree of ammonification realized during the transfer of the effluent in the network [18]. The nitrogen is found in sewage network under its two reduced forms (organic and ammoniacal). The transit through the network modifies their proportions in favor of the ammoniacal form. According the dwell time and temperature, the proportion of ammoniacal nitrogen at the inlet of the treatment plant varies between 50% (short networks) and 75% (very long networks) [9]. Therefore, a ratio value NH_4/NTK found of 0.53 translates a flow of the raw water through a network relatively short.

NH_4/COD: This ratio is of 0.05 and is lower than the value of 0.1 found by [20] that can be considered as characteristic of domestic wastewater.

TSS/COD: The average value recommended by the authors is 0.5 [7,21]. The found value of this ratio, 0.77, is high. Reference [20] 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 network).

TSS/BOD_5: According to [22], the classical value for domestic wastewater of this ratio is between 0.8 and 1.2 and informs on the production of sludge, "natural" fraction brought by the TSS already present in the raw water. It indicates the apportionment of particulate pollution and dissolved pollution. The average value of 1.36 indicates that the pollution is more granular than dissolved that characterizes an essentially unitary network. This value is comparable with the ratio TSS/BOD_5 found of 1.84 by [16]. The recorded variations between 0.8 and 2.22 can be attributed to the phenomenon of sedimentation–erosion within the network.

BOD_5/TKN: For a strict urban effluent, this ratio varies between 4 and 5. It indicates the relative mixity of the effluent and has an impact on the dimensioning of the biological reactor in case of treatment of nitrogen (nitrification) [18]. A value found of 6.34 is slightly higher than those usually encountered (4–5).

BOD_5/TSS: This ratio found 0.73, comparable with 0.75 found by [20]. The extreme values of this ratio vary between 0.45 and 1.24, and are attributable to the sedimentation–erosion phenomenon in the network. It is therefore important to retain that, at some sludge age, the applicable maximum mass load depends on the BOD_5/TSS ratio of the input for which an average value of 1.0 is generally retained for urban wastewater [10].

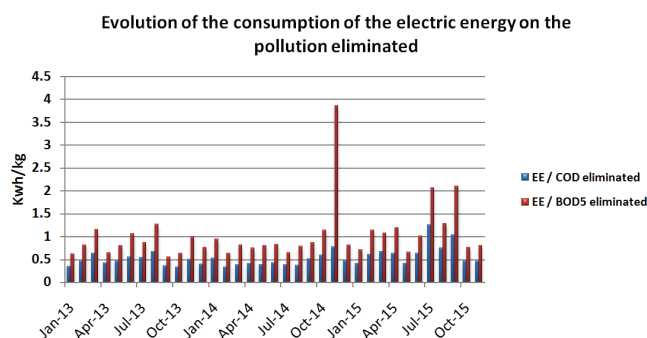**Evolution of the consumption of the electric energy on the pollution eliminated**

Fig. 4. Variations of reports: EE/BOD$_5$ eliminated and EE/COD eliminated.

COD/TSS: This ratio varies from 0.87 to 2.07 with an average of 1.3, less than 1.62 found by [20]. It represents the content of COD in the particles.

TKN/BOD$_5$: Evolves between 0.10 and 0.27 with an average value of 0.16. The kinetics of denitrification depends on this ratio [18].

3.3. Electrical energy consumed

The average value of the electrical energy consumed is 3,210 kWh/d. The mass of pollution eliminated in terms of the BOD$_5$ and COD is, respectively, 3,638.67 and 6,562 kg/d.

The amount of energy required to eliminate the pollution rises to 0.88 kWh/kg of BOD$_5$, yet it is 0.49 kWh/kg of COD. The maximum value of EE/BOD$_5$-eliminated ratio (electric energy/BOD$_5$ eliminated) of 3.85 recorded during the month of November 2014 and the values of 2.07 and 2.10, respectively, recorded during the months of July and September 2015 (Fig. 4) are excessive and exceed the usual values for the spinneret of activated sludge that are of 2 kWh/kg BOD$_5$ eliminated [23]. Because of the high specific consumption, it is recommended to perform an energy diagnosis of the WWTP.

4. Conclusion

The main objective of our study was to adopt a comprehensive approach to control the sanitation system, the evacuation and treatment processes. For this, we have used reliable hydraulic values and monitoring of the main physico-chemical pollution parameters. Starting from a series of consequent data during 3 years: 2013, 2014 and 2015, this study was allowed to determine the average values, minimum and maximum values, ratio and concentration ranges characterizing domestic wastewater of the Medea city.

The study also helped to determine the variation range of the pollution parameters and the various relationships that exist between them. The analyses results have identified gaps and helped to improve evacuation yields and wastewater treatment installations of Medea.

At hydraulic level, the wastewater average flow incoming to the WWTP is 51% of the nominal capacity, but we met an excess flow for some days in September, October and December 2013. As long as the nominal capacity is not reached, such peak loads should be absorbed by the

WWTP without any problem. The dilution rate of wastewater found of 14% caused by the CPW that may bring about malfunction of structures requires significant care and a permanent diagnosis of sewerage network of the Medea city. The reinjection of this CPW to the natural environment should be privileged wherever it is possible, upstream of the WWTP and at the level of storm overflows to improve the sewerage system performance and reduce the cost of exploitation. Good management of WWTP must go in the future through better knowledge and control of the water evacuation network.

For the treatment monitoring of pollution parameters, the removal yields of TSS, COD and BOD$_5$, respectively, 95.35%, 96.31% and 91% reflect the efficiency of treatment applied to the WWTP although we recorded exceedances average concentration of COD and BOD$_5$, which are, respectively, 109% and 104% of nominal values.

The nitrogen treatment reveals that the average concentrations of ammonia NH$_4$–N vary from 29.36 to 3.46 mg/l from the inlet to the outlet. However, nitrates NO$_3$–N increase from 0.59 to 10.61 from the inlet to the outlet of the WWTP, due to nitrification. To better control and mitigate, the nitrates at the outlet of the city WWTP, it is necessary to reduce the daily aeration duration, increasing the denitrification duration in anoxic.

For a BOD$_5$ of 352.33 mg/l, the average values recorded of 29.36 mg/l NH$_4$–N and 2.29 mg/l PO$_4$–P indicate a deficit of 35% for PO$_4$–P and an increase of 67% for NH$_4$–N, relative to the respective theoretical ratios BOD$_5$/NH$_4$–N/PO$_4$–P: 100/5/1 relating to bacterial metabolism. This imbalance into nutrients can be an obstacle at the level of biological treatment.

With regard to the ratios, it is observed similar average values and sometimes comparable with those of the literature. The particularity comes from the high values of the ratios TSS/COD and TSS/BOD$_5$ found, respectively, 0.77 and 1.36, thus translating pollution of a particulate character. A quantitative study would be carried out to complete these results, in particular to evaluate the influence of collection networks on the quality of raw domestic sewage.

The high values of the required electrical energy for the elimination of pollution recorded during the months of November 2014, and July and September 2015, causing exceedances in specific energy consumption require to perform a diagnostic analysis of the facility.

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