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Physico-chemical characterization of domestic wastewaters in the "Vie-Nouvelle" agglomeration, Cotonou, Benin

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ABSTRACT

Wastewaters are characterized by a high variability of flow and composition according to its origin. The objectives of this study were to evaluate the daily variation of the pollutants load from domestic wastewater in "Vie-Nouvelle" agglomeration in the city of Cotonou. In practice, samples were collected over 24 hours with one sample every hour, at the entrance of wastewater treatment plant of the agglomeration. Various parameters were measured at laboratory. Determination of methods specific to each parameter was used. The results show that these wastewaters are characterized by a great pollution variability during the diurnal period of day. The pollutant load showed the following variations : pH values ranging: 7.1 – 7.3 (7.2 ± 0.1 for average); conductivity: 555 - 953 (804 ± 112) µS/cm; turbidity:139 - 238 (192 ± 27) NTU; COD: 675 - 1,983 (1,250 ± 350) mg O_2/l; BOD_5: 261 - 440 (1,257 ± 350) mg O_2/l; NH_4^+: 18 - 34 (24 ± 5) mg/l; N_{TK}: 36 – 78 (57 ± 12) mg/l; PO_4^{3-}: 6 – 18 (13 ± 4) mg/l; P_T: 6 – 18 (13 ± 4) mg/l; Al: 3,998 – 8,508 (5,990 ± 1,338) µg/l; Cd: 0.5 – 6 (2 ±1) µg/l; Co: 1 – 3 (1 ± 1) µg/l; Cr: 19 – 110 (40 ± 25) µg/l; Cu: 113 – 615 (224 ± 135) µg/l; Fe: 3,232 – 16,842 (6,905 ± 3,846) µg/l; Mn: 114 – 452 (211 ± 90) µg/l; Ni: 18 – 85 (36 ± 17) µg/l; Pb: 52 – 243 (101 ± 50) µg/l; and Zn: 411 – 2,490 (908 ± 538) µg/l. These wastewaters do not comply with the discharge standards. They are moderately biodegradable and required denitrification and dephosphatation treatment processes before their release into aquatic ecosystems.

Keywords: Domestic wastewater, wastewater variation, daily variation, pollution load, physico-chemical parameters.

INTRODUCTION

Urban wastewater has been the subject of many studies, mainly due to its negative impacts on the environment (Youssao et al., 2011; Gasperi et al., 2012; Saïzonou et al., 2014 ; Camocho-Munoz et al., 2014; Diagne et al., 2017). Several of these studies have focused on the characterization of wastewater from various production sources such as bathrooms or toilets, laundries, kitchen, runoff or stormwater, urban wet and dry sewage, influent of wastewater treatment plant, greywater, etc. (Kafi et al., 2008; Gasperi et al., 2012 ; Sawadogo et al., 2012). Depending on their origin, wastewaters are characterized by high variability in flow and composition due to population density and mobility, dietary habits, lifestyles, habitat types, socio-economic and climatic factors (Henze et al., 2008; Rodier et al., 2016). Toilets are the

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main sources of urban wastewater in pollutants, particularly in ammonium. Other studies made on unit sewers revealed that pollutant loadings related to suspended solids, bound metal particles, organic materials, aliphatic hydrocarbons and polycyclic aromatic hydrocarbons (PAHs) had similar evolutionary trends during wet weather as those observed in dry weather; but these pollutants loads were higher than those observed in runoff water. So, the main part of the wet weather pollution originates from the combined sewer itself, which is an important source of particles and of organic matter, suggesting that these pollutants originated from the erosion of in-sewer deposits (Kafi et al., 2008; Gasperi et al., 2012). Kafi et al. (2008) noticed that total Kjeldahl nitrogen concentrations were lower during wet weather than those in dry weather. In addition, according to studies carried out by Kafi et al. (2008) in one side, and Rule et al. (2006) in another one, concentrations of metallic pollutants in runoff are higher than those observed in domestic wastewaters and exhibit the highest values at the onset of rainfall events with the highest suspended solids concentrations. Wastewaters in wet weather (in unitary network) have higher concentrations for most hydrophobic organic pollutants and some particulate-bound metals than in wastewaters of dry weather and in runoff waters, due to the contribution of erosion of deposits of sewers (Gasperi et al., 2012).

Furthermore, many studies revealed that the daily variation of wastewaters flows and pollutants content depend on the populations activities during all day. In this sense, Gernaey et al. (2011) and Saagi et al. (2016) have indicated an appearance of the pollution peaks in the early morning and early evening. Overnight, concentrations of pollutants declined sharply in water due to low wastewater production and also because, pollutants subjected to low flows are deposited in the pipelines. However, the occurrence time of wastewater production peaks may vary according to the agglomerations size and socio-economical characteristics. In large urban areas, there is often a single peak in wastewater production, which can be explained by the fact that the more the city is large, the more its wastewater is balanced in terms of quantity and composition (Degremont, 2005). It is also observed that wastewater flows and their chemical composition decrease during the weekdays compared with the weekend days (da-Silva, 2008; Cipolla et al., 2009; Eriksson et al., 2009; Camacho-Munoz et al., 2014). The study of the daily variation of wastewater flow and chemical composition is useful since the analysis of hydrographs and pollutographs allow getting important informations to predict wastewater production (Saagi et al., 2016). Nowadays, this prediction is necessary to cope with large-scale measurement campaigns and their high cost.

In Benin, studies on wastewaters provide mainly informations on the pollutants load and less or not at all on the daily variation of these wastewaters flow and chemical composition (Saïzonou et al., 2014; Adjahouinou et al., 2014). Thus, the objectives of this work are to evaluate the daily variation of the pollutants load from domestic wastewaters in "Vie-Nouvelle" agglomeration in the city of Cotonou. The results could be used to design a suitable treatment system for these wastewaters in the short to medium term.

MATERIALS AND METHODS

Description of study area

"Vie-Nouvelle" is a small agglomeration located on the edge of the Atlantic Ocean in the south east of Cotonou city. It is made up of 50 villas and 316 apartments which were constructed by the Benin Government in the 1970s (Seureca, 2015). This city covers spaces where habitat is low and streets are narrow. We can count approximately 1,200 population equivalent (PE) which are connected to a collection and treatment system for the domestic wastewater (greywater and septic wastewaters) (Seureca, 2015). For different uses, residents of the "Vie-Nouvelle" agglomeration are supplied in water from SONEB (Société Nationale des Eaux du Benin; National Society for Waters in Benin), potable water distribution network and also from very shallow domestic wells. The treatment system for wastewaters is made up of : i) a separate wastewaters collection sewer which is about 1.8 km long and 200 mm diameter consisting in a set of 110 sumps distributed between apartments and connected to each other by drainage pipes; ii) a small treatment plant made up of a 30 m^3 capacity basin housing a submersible motor pump ; a large aeration basin with approximately 1,152 m^3 capacity ; an engine room housing an electric control cabinet and a drying bed; iii) an outlet which is the sea (Seureca, 2015). We can mention that the treatment plant is not actually functional (since the 1990s) and just represents a transit site for the wastewaters which, without being treated, finally releases into the sea. For wastewaters evacuation, a vacuum pump operates 12 hours of time per day with 9.5 m^3 of evacuated water per hour, or approximately 114 m^3 of evacuated water per day (Seureca, 2015).

A typical subequatorial climate with an alternation of dry and wet seasons characterizes the study area: a great rainy season, a small dry season, a small rainy season, and a great dry season. Rainy events occur mainly between March and July with maximum precipitations in June (300-500 mm) (INSAE, 2005). Annual average (1981 to 2010) is 1,308 mm of rainfall (http://www.meteofrance.com/climat/monde/cotonou/0065344).The monthly average temperature varies between 27 °C (February-April period) and 31 °C (July-September period) (INSAE, 2005).

Sampling

A continuous sampling has been carried out hourly for 24 hours (one sample every hour), at the entrance of wastewater treatment plant of "Vie-Nouvelle" agglomeration, using an "Avalanche" automatic sampler (Rodier et al., 2016; AFNOR, 2001a). At each sampling cycle, 900 ml (volume of the polyethylene bottle in automatic sampler) of sample were taken, stored at 4 °C and transported to the laboratory for analysis within 24 hours (Rodier et al., 2016 ; AFNOR, 2001a). Six sampling campaigns were conducted from October to December 2016. This sampling period corresponds almost to the end of the small rainy season until the middle of the great dry season. The wastewater treatment plant which is the sampling site is indicated on the administrative map of Cotonou (Figure 1).

Laboratory analysis

Physico-chemical parameters such as : pH, turbidity, electrical conductivity, biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), ammonium (NH_4^+), Kjeldahl total nitrogen (N_{TK}), orthophosphate (PO_4^{2-}), total phosphorous (P_T), major elements Calcium (Ca^{2+}), Magnesium (Mg^{2+}), Potassium (K^+), Sodium (Na^+), metals aluminum (Al), cadmium (Cd), cobalt (Co), chromium (Cr), manganese (Mn), nickel (Ni), lead (Pb), iron (Fe) and zinc (Zn) were used to characterize the wastewater samples. Table 1 exhibits the analytical methods and related technical equipments used for the measurements of the wastewater physico-chemical characteristics according to NF-EN-ISO (French Standards; European Standards and International Organization for Standardization) (AFNOR, 2001b ; AFNOR, 2001c; Rodier et al., 2016).

Data analysis

In order to appreciate the variation of the wastewater pollutant loads, the hourly means of the measured values for each parameter were computed and used to draw the pollutographs. These graphs show or allow analyzing the mean daily variations and the magnitude of pollutants loads. In addition, the Pearson correlation and the test of Student, statistics were used to assess the inter-parameter correlations. The test was used at the 5% threshold for the statistical significance of the correlations. Microsoft excel is the software used for the various calculations, the elaboration of the graphs and the statistical analyses.

The characteristics ratios of wastewater such as DCO/DBO_5, DBO_5/N_{TK}, DBO_5/P_T, DCO/N_{TK}, DCO/P_T, NH_4^+/N_{TK}, PO_4^{3-}/P_T, MES/DBO_5 were calculated from the means values of some parameters. They make it possible to characterize the eutrophic and biodegradable nature of the wastewaters.

Table 1: Materials and methods used for physicochemical analysis in this study.

Pollution parameters	prior Filtration with 0.45 µm membrane	prior Digestion with nitric acid (d= 1.40 ; 65%)	Methods of analysis	Measuring instruments	Standards
pH	No	No	Potentiometric method	"WTW 3310" pH-meter	NF-T 90-008 ; NF EN ISO 10523
Conductivity (µS/cm)	No	No	Electrometric method	"WTW 3401" conductivity-meter	NF-EN 27888 ; ISO 7888
Turbidity (NTU)	No	No	Nephelometric method	"Wagtech" turbidimeter	NF–EN-ISO 7027
Biochemical Oxygen Demand (mg/l)	No	No	Respirometric method at 20°C	Oxytopes and incubator "WTW"	NF-EN 1899-1 / 2 (classification index T 90-103-1)
Chemical Oxygen Demand (mg/l)	No	No	Potassium-dichromate oxidation at 150°C ; Reflux method in open system with spectrophotometer	"HACH LANGE DR 2800" spectrophotometer and "HACH" reactor	NF–T 90-101
Ammonium (mg/l)	Yes	No	Nessler's reagent spectrophotometry method	"HACH LANGE DR 2800" spectrophotometer	NF–T 90-015
Kjeldah Total Nitrogen (mg/l)	Yes	No	Nessler's reagent spectrophotometry method after digestion with sulfuric acid	"HACH LANGE DR 2800" spectrophotometer	NF–EN 12260 ; NF-T 90-015-2
Total Phosphorus (mg/l)	Yes	No	PhosVer 3 method with spectrophotometer detection after digestion with sulfuric acid and neutralization	"HACH LANGE DR 2800" spectrophotometer	Method 8048 Hach Company
Cations (Ca^{2+}, Mg^{2+}, K^{+}, Na^{+}) (mg/l)	Yes	No	Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES)	"Thermo-scientific ICAP 6000 series" spectrometer	NF-EN-ISO 11885
Heavy metals (Al, Cd, Co, Cr, Cu, Mn, Ni, Pb, Zn) (µg/l)	No	Yes	Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES)	"Thermo-scientific ICAP 6000 series" spectrometer	NF-EN-ISO 11885

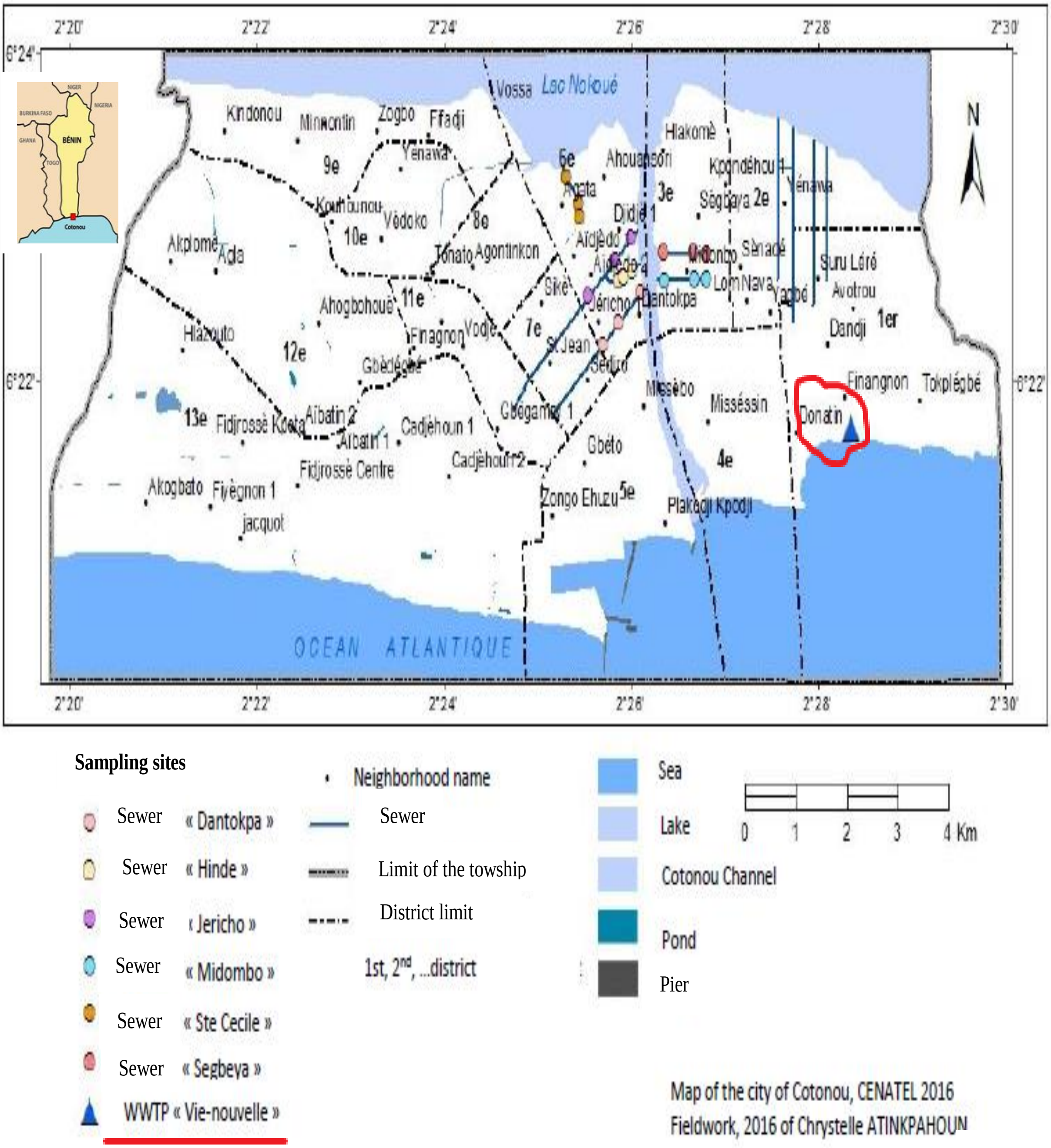

Figure 1: Location of the sampling site on the map of Cotonou.

RESULTS

The physico-chemical results as well as the calculated characteristic ratios were analyzed statistically and indicated in Table 2. The graphs in Figures 2 to 6 show the daily profiles of these parameters. The matrix of inter-parameter correlation is presented in Table 3.

Daily variation for global physico-chemical parameters

From the analysis of the graphs of Figures 2 to 6, we have the following observations:

- all parameters show great variability throughout the day ;
- the period from 6:00 am to 8:00 pm is characterized by a great variability compared with the nocturnal period from 8:00 pm to 6:00 am for all parameters, except for the COD and the BOD_5 which on the other hand, show a greater variability throughout the day ;
- the parameters such as SS, NH_4^+, N_{TK}, PO_4^{3-}, P_T, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, and Zn, have their concentrations dropping overnight, in accordance with the typical profiles of wastewater variation (Botho et al., 1990).
- contrary to the parameters previously mentioned, pH, turbidity, COD and BOD_5 show, during the night period, their high rates to those of the diurnal period which is not in accordance with the typical variation of urban wastewater.

Pollution loads of physico-chemical characteristics

pH and conductivity (Figure 2)

The pH values range from 7.1 to 7.3 (Table 2). These values exhibit low coefficients of variation (1%) (Table 2). They are slightly higher than those of wastewaters in university residences of Abomey-Calavi in Benin (Hounkpe et al., 2013).

The electrical conductivity values range from 551 to 953 µS/cm with an average of 804 ± 112 µS/cm and a median value of 847 µS/cm. A comparison with the wastewaters from university residences of Abomey-Calavi in Benin (Hounkpe et al., 2013) and with that of " Grand-Nancy" in France (Le, 2013) shows that the wastewaters from the "Vie-Nouvelle" agglomeration are less mineralized. But this mineralization level is higher than that of Ormes’s wastewaters in the Orleans urban area in France (Juhaishi et al., 2016).

Suspended solids (SS), turbidity, chemical oxygen demand (COD) and biochemical oxygen demand (BOD_5)

The suspended solids (SS) values range from 211 to 509 mg/l with an average of 346 ± 75 mg/l and a median value of 344 mg/l (Table 2). The SS contents are higher than those in wastewaters from Abomey-Calavi university residences (Hounkpe et al., 2013), as well as wastewaters from "Grand-Nancy" (da-Silva, 2008) and from small communities having below 2000 PE in France (Mercoiret, 2010).

The turbidity values are between 139 and 238 NTU with an average of 192 ± 27 NTU (Table 2). They are higher than those observed by Le (2013) in the "Grand-Nancy" wastewaters in accordance with the high suspended solids contents above mentioned.

The COD vary from 675 to 1,983 mg/l with a mean value of 1,257 ± 350 mg/l (Table 2) while the BOD_5 values range from 261 to 440 mg/l with an average of 350 ± 49 mg/l (Table 2). In spite of the high values of COD and BOD_5, in the wastewaters from "Vie Nouvelle" agglomeration, a high variability is observed along the day. The rates of COD are considerably higher than those measured in septic and grey waters from Abomey-Calavi University residences. The BOD_5 values of these residences samples are similar to those measured in septic wastewaters and exhibits rates considerably higher than those in greywaters (Hounkpe et al., 2013). These rates are higher than those in wastewaters from "Grand-Nancy" (da-Silva, 2008) and domestic wastewaters of small communities in France (Mercoiret, 2010) (Figure 3).

Ammonium, Kjeldahl total nitrogen (N_{TK}), and total phosphorus (P_T)

Ammonium ion (NH_4^+) and N_{TK} rates range from 18 to 34 mg/l with an average of 24 ± 5 mg/l and from 36 to 78 mg/l with an average of 57 ± 12 mg/l respectively (Table 2). The NH_4^+ ion contents are higher than those in wastewaters from Abomey-Calavi university residences (Hounkpe et al., 2013). Compared with the "Grand-Nancy" wastewaters and with domestic wastewaters from small communities of 2000 PE in France (da-Silva, 2008; Mercoiret, 2010; Le, 2013), the "Vie Nouvelle" wastewaters have lower levels of nitrogenous compounds.

Orthopphosphate ion (PO_4^{3-}) and Total Phosphorus (P_T) rates range from 6 to 18 mg/l with an average of 13 ± 4 mg/l and from 6 to 22 mg/l with an average of 14 ± 4 mg/l respectively (Table 2). The levels PO_4^{3-} concentrations are similar to those of septic wastewaters from Abomey-Calavi university residences, but lower than those of greywaters. The total phosphorus contents are similar to those of greywater but lower than those of septic wastewaters (Hounkpe et al., 2013). When compared with wastewaters from "Grand-Nancy" and from small communities of 2000 PE in France (Mercoiret, 2010), it appears that phosphorus are higher in the "Vie-Nouvelle" agglomeration.

A good statistically significant correlation is observed between ammonium ion (NH_4^+) and each of the three following nutrient parameters (N_{TK}, PO_4^{3-}, total phosphorous) **(**R^2 = 0.7; 0.6 and 0.6 respectively in Table 3). Those nutrients parameters (N_{TK}, PO_4^{3-}**,** P_T and NH_4^+) have a good and statistically significant correlation (coefficient of 0.9, 0.7, 0.8 and 0.8 respectively in Table 3) with electrical conductivity. P_T and N_{TK} are also correlated with SS (0.6 and 0.7, respectively) (Figure 4)

Metals (Figure 6)

Considering the mean values of concentration, a classification in decreasing order gives: Fe > Al > Zn > Cu > Mn > Pb > Cr >Ni > Cd > Co. The "Vie-Nouvelle" wastewaters have high content of micropollutants compared with wastewaters from Abomey-Calavi university residences (Hounkpe et al., 2013).

Characteristics ratios of wastewater

The values of different ratios are presented in Table 2. Among others, the COD/BOD_5 value is higher than 3 and less than 5. The value of BOD_5/N_{TK} ratio is higher than 4 units and those of NH_4^+/N_{TK} ratio lower than 60%. That of BOD_5/P_T ratios is higher than 20 units and that of MES/BOD_5 ratio around 1.

Table 2: Distributions of the physico-chemical data and characteristic ratios for the "Vie-Nouvelle" wastewaters (σ =Standard deviation; CV = Coefficient of variation).

Parameters	Number of measurement campaigns	Minima	Maxima	Average	σ (± x)	CV (%)	Median	1st Quartile	3rd Quartile
Macropollutants									
pH	06	7.1	7.3	7.2	0.1	1	7	7	7
Cond (µs/cm)	06	551	953	804	112	14	847	731	907
Turb (NTU)	06	139	238	192	27	14	197	174	209
MES (mg/l)	06	211	509	346	75	22	344	287	398
COD (mgO_2/l)	06	675	1,983	1,257	350	28	1,280	1,033	1,466
BOD_5 (mgO_2/l)	06	261	440	350	49	14	350	318	388
NH_4^+ (mg/l)	06	18	34	24	5	22	22	21	29
N_{TK} (mg/l)	06	36	78	57	12	21	57	48	65
PO_4^{3-} (mg/l)	06	6	18	13	4	29	13	10	15
P_T (mg/l)	06	6	22	14	4	31	14	10	17
Majors elements (Cations)									
Ca^{2+} (mg/l)	06	34	81	52	12	22	52	44	57
Mg^{2+} (mg/l)	06	6	12	9	1	17	8	7	9
K^+ (mg/l)	06	15	30	25	3	13	25	24	27
Na^+ (mg/l)	06	41	83	70	9	12	69	67	75
Micropollutants									
Al (µg/l)	06	3,998	8,508	5,990	1,338	22	5,695	5,096	6,986
Cd (µg/l)	06	0.5	6	2	1	73	1	1	2
Co (µg/l)	06	1	3	1	1	44	1	1	2
Cr (µg/l)	06	19	110	40	25	61	32	26	44
Cu (µg/l)	06	113	615	224	135	60	177	146	245
Fe (µg/l)	06	3,232	16,842	6,905	3,846	56	5,499	4,608	7,548
Mn (µg/l)	06	114	452	211	90	43	182	160	222
Ni (µg/l)	06	18	85	36	17	49	30	22	42
Pb (µg/l)	06	52	243	101	50	49	90	72	102
Zn (µg/l)	06	411	2,490	908	538	59	699	628	990
Characteristic ratios									
COD/DBO_5	BOD_5/N_{TK}	BOD_5/P_T	COD/N_{TK}	COD/P_T	NH_4^+/N_{TK} (%)		PO_4^{3-}/P_T (%)	MES/BOD_5	
3.59	6.15	27.76	22.05	99.59	43%		108%	0.99	

Table 3: Matrix of inter-element correlation.

	pH	Cond	SS	Turb	COD	BOD_5	NH_4^+	N_{TK}	PO_4^{3-}	P_T	Ca^{2+}	Mg^{2+}	K^+	Na^+	Al	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	Zn
pH	1.0																							
Cond	-0.3	1.0																						
SS	0.1	0.5*	1.0																					
Turb	0.4	0.0	0.4	1.0																				
COD	-0.2	-0.4	0.2	0.0	1.0																			
BOD_5	0.4	-0.3	0.2	0.4	0.4	1.0																		
NH_4^+	-0.4	0.8*	0.3	-0.2	-0.2	-0.4	1.0																	
N_{TK}	-0.1	0.9*	0.7*	0.1	-0.4	-0.3	0.7*	1.0																
PO_4^{3-}	-0.3	0.7*	0.2	-0.2	-0.3	-0.4	0.6*	0.7*	1.0															
P_T	-0.2	0.8*	0.6*	0.0	-0.2	-0.1	0.6*	0.8*	0.5*	1.0														
Ca^{2+}	0.0	0.1	0.7*	0.1	0.5*	0.2	0.0	0.3	0.0	0.3	1.0													
Mg^{2+}	0.3	0.1	0.6*	0.2	0.3	0.2	0.0	0.3	-0.1	0.3	0.7*	1.0												
K^+	0.2	-0.1	0.3	0.2	0.5	0.2	0.1	-0.1	-0.2	-0.1	0.5*	0.6*	1.0											
Na^+	0.5	-0.1	0.2	0.4	0.4	0.2	-0.1	-0.1	-0.2	-0.2	0.4	0.5*	0.8*	1.0										
Al	0.1	0.0	0.5*	-0.1	0.4	0.3	-0.1	0.1	0.1	0.2	0.4	0.4	0.1	0.2	1.0									
Cd	-0.5	0.3	0.6*	-0.2	0.3	0.0	0.3	0.5*	0.3	0.5*	0.8*	0.4	0.2	-0.1	0.4	1.0								
Co	-0.4	0.5*	0.1	-0.1	-0.5*	-0.4	0.3	0.5*	0.2	0.4	-0.1	-0.1	-0.4	0.5*	-0.2	0.3	1.0							
Cr	-0.3	0.4	0.7*	-0.1	0.2	0.0	0.4	0.5*	0.3	0.5*	0.8*	0.5*	0.2	0.0	0.5*	0.9*	0.2	1.0						
Cu	-0.3	0.4	0.7*	-0.1	0.2	0.0	0.4	0.5*	0.3	0.6*	0.8*	0.6*	0.3	0.0	0.5*	0.9*	0.3	1.0*	1.0					
Fe	-0.4	0.4	0.8*	-0.1	0.3	0.0	0.4	0.5*	0.3	0.6*	0.8*	0.5*	0.2	-0.1	0.5*	0.9*	0.2	1.0*	1.0*	1.0				
Mn	-0.3	0.4	0.8*	-0.1	0.2	0.0	0.4	0.6*	0.3	0.6*	0.8*	0.5*	0.2	-0.1	0.4	0.9*	0.2	1.0*	1.0*	1.0*	1.0			
Ni	-0.1	0.2	0.6*	0.1	0.4	0.3	0.2	0.4	0.1	0.4	0.7*	0.4*	0.4	0.1	0.3	0.8*	0.0	0.9*	0.8*	0.8*	0.8*	1.0		
Pb	-0.4	0.2	0.5*	-0.2	0.2	-0.1	0.2	0.4	0.1	0.3	0.7*	0.5*	0.2	-0.1	0.3	0.9*	0.4	0.9*	0.9*	0.9*	0.9*	0.7*	1.0	
Zn	-0.4	0.4	0.7*	-0.1	0.2	0.0	0.4	0.5*	0.3	0.6*	0.8*	0.5*	0.3	0.0	0.5	0.9*	0.2	1.0*	1.0*	1.0*	1.0*	0.8*	0.9*	1.0

(*) correlations are statistically significant at 5%

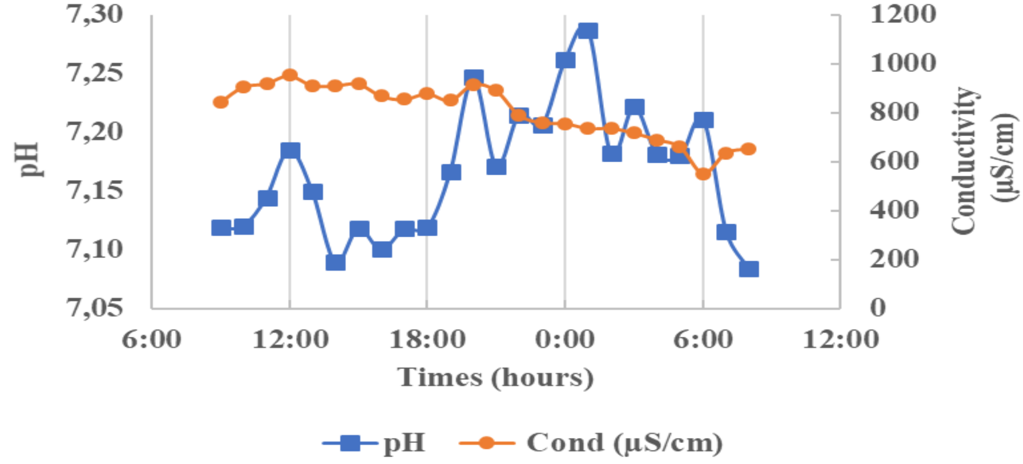

Figure 2: Daily variation of pH and electrical conductivity.

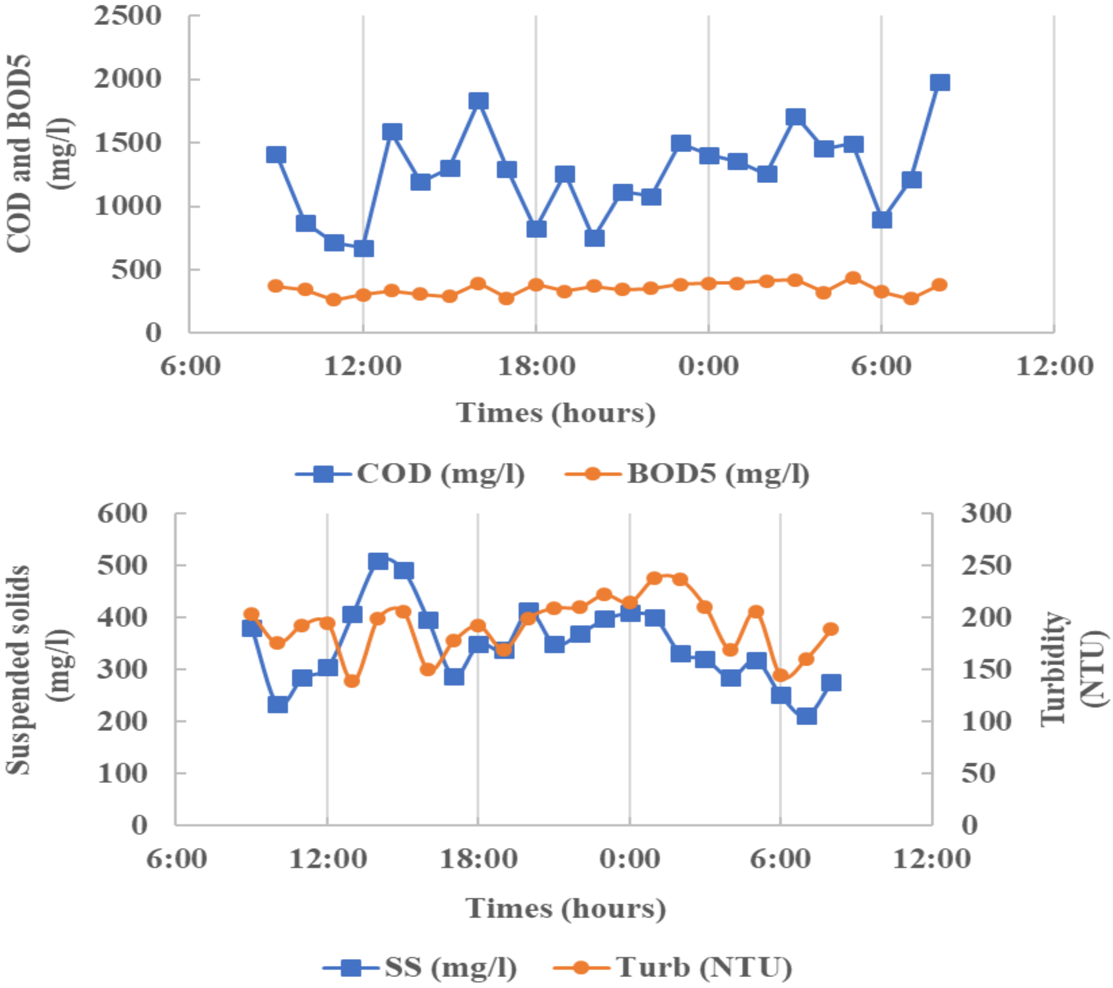

Figure 3: Daily variation of Suspended Solids, Turbidity, COD and BOD_5.

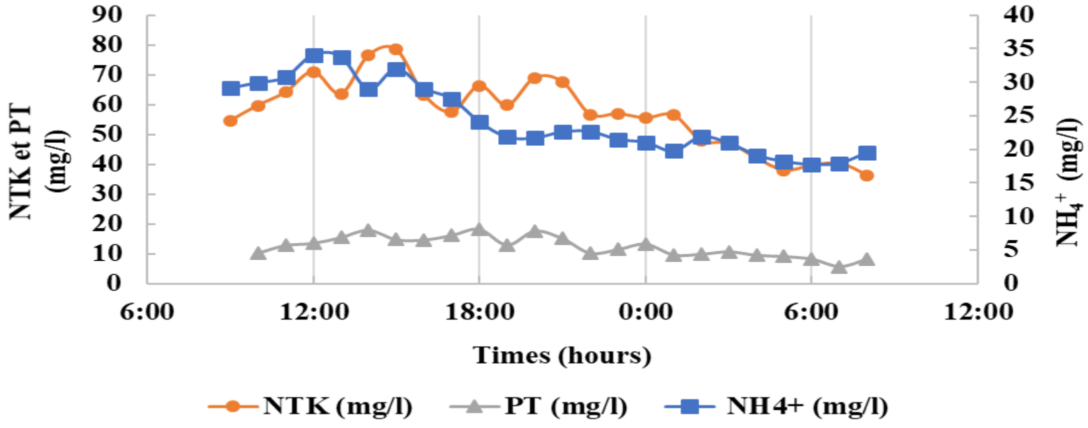

Figure 4: NH_4^+, N_{TK} and P_T daily variation.

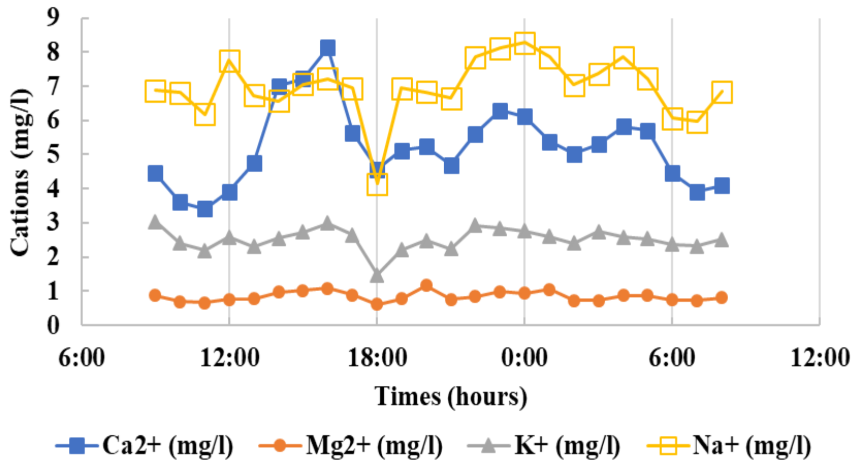

Figure 5: Majors elements daily variation.

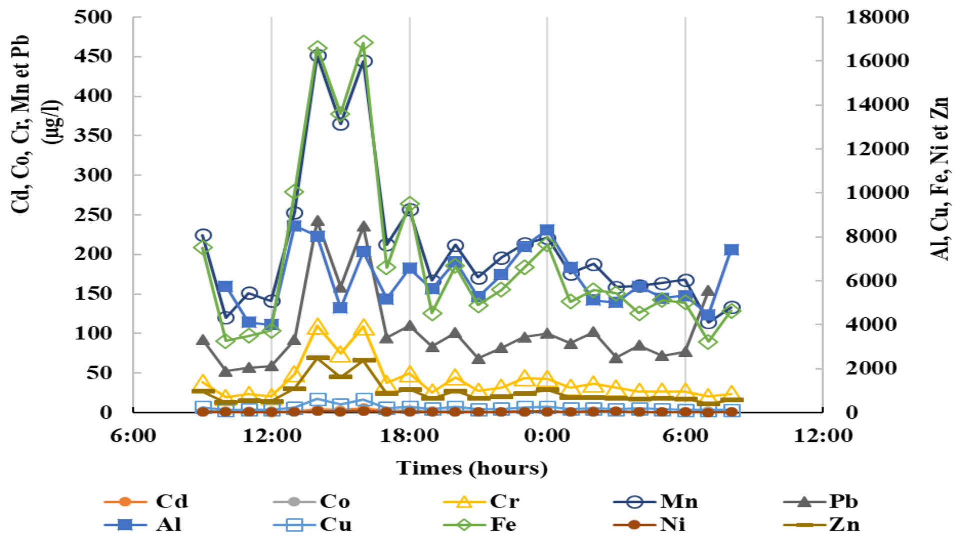

Figure 6: Metal daily variation.

DISCUSSION

Daily variation for global physico-chemical parameters

The daily variation of wastewater pollutant contents depend on the populations activities during the whole day. Concentration peaks during the day correspond to periods of high water consumption, accompanied by water pollution (Gernaey et al., 2011). The nocturnal period, which corresponds to the sleeping time, is characterized by low consumption of water accompanied by low release of wastewater and pollutants, contrary to what happens during the day (Gernaey et al. 2011). But the rates of COD and BOD_5 in the nocturnal period are not in accordance with the typical variation of urban wastewater. This situation is similar to results obtained by Ericksson et al. (2009) with organic loads during periods of low flows and could be explained by the low water consumption at night as well as the low wastewaters production which reduces the dilution effect.

Pollution loads of physico-chemical characteristics

pH and conductivity

The pH values indicated almost neutral aqueous solution in accordance with national (RB, 2001) and international wastewater discharge standards (5,5 ≤ pH ≤ 9,4) (RM, 2014 ; ISN, 2001 ; CEC, 1991), and also with most studies on wastewater (Raweh et al., 2011). The coefficient of variation (1%) reflects a buffering capacity for the wastewater (Rodier et al., 2016). These pH values obtained for wastewaters samples are favorable for the growth of the bacteria that ensure biodegradation (Rodier et al., 2016).

According to Rodier et al. (2016), these electrical conductivity values are characteristic of highly mineralized wastewater whose origin could be related to the high contents of organic and suspended matters. These values of conductivity are in accordance with Morroco’s standards (Conductivity ≤ 2700 µS/cm) (RM, 2014). The differences observed in the various watersheb could be related to the chemical quality of the water consumed for domestic uses and to the quality of the soils leachates entering in the sewers.

Suspended solids (SS), turbidity, chemical oxygen demand (COD) and biochemical oxygen demand (BOD_5)

These median and average values of SS are not in accordance with Benin and international standards (35 mg/l ≤ SS ≤ 100 mg/l). Most of suspended particles could derive from the urban runoff that enters the outdated sewers. As Bertrand-krajewski (2006) was suggesting from many earlier studies, these suspended solids could be much more constituted of mineral solids such as calcium and magnesium precipitates. This could explain the good statistically significant correlation of SS with Ca^{2+} and Mg^{2+} ions (R^2 = 0.7 and 0.6 respectively in Table 3).

Compared with wastewater discharge standards of Benin and of international (125 mg/l ≤ COD ≤ 500 mg/l and 25 mg/l ≤ BOD_5 ≤ 100 mg/l), the COD and BOD_5 values are disagreed. The high organic loads could be attributed to bulk release of liquid and solid wastes from household and artisanal activities (automobile and motorcycle repair shops, etc.).

Ammonium, Kjeldahl total nitrogen (N_{TK}), and total phosphorus (P_T)

The mean values exceeds the discharge limits (10 mg/l ≤ N_{TK} ≤ 40 mg/l ; 1 mg/l ≤ P_T ≤ 15 mg/l). These characteristics in the different watersheb of comparison, with regard to nitrogen pollution could be explained by the differences between wastewaters management strategies. Indeed, in developed countries, almost all human rejections (containing high amount of nitrogen) are collected and directed to the treatment plants, while in developing countries like Benin, human wastes are discharged everywhere in the environment. This situation may explain the lower ammonium content in the study area sewers. The difference could also be related to the number of population equivalent connected to the wastewater treatment plant. In France, wastewaters have registered a gradual decrease in phosphorus contents since the 1990s due to the decrease in the use of laundry containing phosphates (Mercoiret, 2010).

So, nitrogen and phosphorus pollution could have the same sources which are probably human dejections. Actually, nitrogen pollution comes mainly from urine and feces whereas phosphorus pollution derives from human dejections (30-50%) as well as cleaning products (Rodier et al., 2016). These strong correlations of these parameters with conductivity indicate the influence of nutrients pollution on wastewater mineralization.

Metals

With the exception of iron, the concentrations of metals are in accordance with Moroccan standards (Al ≤ 10 mg/l, Cd ≤ 0,25 mg/l, Co ≤ 0,50 mg/l, Pb ≤ 1 mg/l, Cr ≤ 2 mg/l, Mn ≤ 2 mg/l, Ni ≤ 5 mg/l, Zn ≤ 5 mg/l, Fe ≤ 5 mg/l and Cu ≤ 2 mg/l). The results could indicate that heavy metals come from mainly out of households and/or subject to sorption processes with SS. The leaching of roofs and pavements could be the main sources of heavy metals (Bertrand-krajewski, 2006).

Characteristic ratios of wastewaters

The COD/BOD_5 value indicating that, the studied wastewaters are moderately biodegradable (not easy biodegradable) (Le Pen et al., 1998; Sadowski, 2002; Rodier et al., 2016). This could be related to the rain-seepage intrusion from roofs and roads into the old sanitary sewers at the site, which could help increase the loads which are not biodegradable or slowly biodegradable organic materials.

The value of BOD_5/N_{TK} ratio indicates that these wastewaters do not have a nitrogen deficiency (Le Pen et al., 1998) and the value of ratio NH_4^+/N_{TK} (≤ 60%) indicates that they do not require nitrification (conversion of ammoniacal nitrogen to nitrite and to nitrate). Indeed, these wastewaters also contain ammonium, nitrite and nitrate which would be in significant quantity. They require denitrification according to the value of ratio $COD/N_{TK} > 10$ (Le Pen et al. 1998).

The values of BOD_5/P_T ratios suggest a phosphorous enrichment of wastewater. The values of PO_4^{3-}/P_T ratio > 75%, signifies that a dephosphatation is requested, but biological dephosphatation is not adapted because of the values of COD/P_T ratio higher than 50 units (Le Pen et al., 1998). Besides, the values of MES/BOD_5 ratio around 1 obtained in this study indicate an excess of sludge in wastewaters (Sadowski, 2002).

Also, the physico-chemical characteristics obtained and compared with the typical composition of urban wastewaters (Henze et al. 2008) show that the wastewater from "Vie-Nouvelle" agglomeration could be classified into two categories. They belong to high concentrated wastewaters class in relation to organic pollution and micropollutant pollution although the concentrations of these metals are not yet critical, as well as and to medium concentrated wastewaters class in regard to nitrogen and phosphorus pollution). This situation corresponds to a low water consumption situation (Henze et al., 2008). In the east area of Cotonou where the “Vie-Nouvelle" agglomeration is located, water consumption level is evaluated at 60 liters/inhabitant/day (Seureca et al., 2014). This water consumption is low compared with that of developed countries. For example, in France, the average water consumption is about 150 liters/inhabitant/day. (https://www.planetoscope.com/consommation-eau/243-litres-d-eau-consommes-par-un-francais.html).

Conclusion

The pollutographs of wastewaters from "Vie-Nouvelle" agglomeration globally show a great variation over the day. The concentrations of the physico-chemical parameters are not in compliance with discharge standards, especially in regard to macropollution. These wastewaters require adequate treatment before rejection in the environment. The biodegradability and eutrophicating potential characteristic ratios suggest moderately (not easily) biodegradable materials that require denitrification and dephosphatation processes. However biological dephosphatation may not be suitable.

COMPETING INTERESTS

The authors declare that they have no competing interests.

AUTHORS' CONTRIBUTIONS

CNHA collected, processed data and wrote the article; HHS, MNP and J-PL supervised the data collection and participated in article writing.

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