Environment, Development and Sustainability (2021) 23:4342–4356
https://doi.org/10.1007/s10668-020-00777-z

Degradation of the macro-drainage water quality of an urban basin in Northeastern Brazil

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Received: 6 January 2020 / Accepted: 14 May 2020 / Published online: 1 June 2020

Abstract
The growth of cities allied to the lack of investment in urban infrastructure has caused the deterioration of the environment and natural resources. In this context, illegal connections of sewage in rainwater drainage systems has become increasingly frequent, thus compromising the water quality of the same. Campina Grande, located in the state of Paraíba, northeastern Brazil, has been affected by this problem and, therefore, this work aims to evaluate the pollution in its macro-drainage system, within the urban basin of the Prado creek. For that, were analyzed quality indicators of water samples collected at eight points distributed along the Prado creek. In addition, a study was carried out regarding the canal's self-purification capacity in front of the entire wastewater discharge. Through the laboratory analyzes, it was proven that the drainage water of the Prado canal presents typical concentrations of sanitary sewage with high polluting potential. The points that presented critical quality were: two and four, these being the places with priorities for interventions in the short term. It was noted that, across of the dissolved oxygen profile along the canal, it was verified that the self-purification capacity of the canal was largely exceeded.

Keywords Urban basins · Drainage system · Water quality · Self-purification

1 Introduction

Urban rainwater should be used as a resource for potable and non-potable water supply within cities and other urban areas (Sidhu et al. 2012). However, in most cases, they contain a variety of chemicals, nutrients, metals, fecal material of human and animal origin and others. There are a number of barriers to the reuse of rainwater for potable and non-potable purposes in urban residential areas. The most significant problem may be associated with the presence of pathogens, potentially originating from human sewage contamination (Sauer et al. 2011).

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In urban areas with a certain degree of consolidation, due to factors related to urban infrastructure inefficiency and socioeconomic and cultural conditions, urban drainage systems have become a way of transporting domestic effluents to watercourses. According to Araújo (2016), this practice is harmful, since the network is not designed for such action nor does it have treatment units. Therefore, the entire organic load will compromise the quality of the water in the drainage system, as well as in the interconnected water resources.

Chamun (2008) emphasizes that the quantification of the pollutant load affluent to a water body is a fundamental element for any management that aims at the sustainable use of water and its conservation. According to Von Sperling (2014a), by means of this quantification, it is possible to evaluate the impact of the pollution and the effectiveness of the control measures, being necessary field surveys in the area of study, including pollutant sampling, laboratory analysis, and flow measurement.

Sometimes the wastewater is also released directly into the water bodies before any treatment for disinfection or decontamination. These are highly harmful practices not only because they reduce the time of the "urban hydrological cycle," but also because they are responsible for the degradation of water quality in the urban environment (Botelho 2011).

In addition to these liquid wastes, the drainage canal suffers an anthropic pressure on the amount of solid waste by part of the population that, inappropriately, uses your gutters and margins as disposal sites of their solid waste, which implies a compromise in their operation (SMDU 2012).

In view of the complexity of the occupation of the urban space, it is necessary to search for mechanisms that allow quick and low-cost responses to the quality of surface runoff and involving the stages of development of an urban basin. Associated with the complexity of basin occupation, problems are often encountered when considering the difficulties in creating mechanisms to monitor the quality of drainage water with a scientific-theoretical basis, in which it is sought to better understand the phenomena of diffuse pollution (Gomes 2014).

Therefore, the present study has the purpose of evaluating the pollution in the macro-drainage system of the city of Campina Grande, state of Paraíba, northeastern Brazil, within the urban basin of the Prado creek, based on water quality indicators, with a view to suggest planning actions, as well as the adoption of enforcement and punitive measures that help both the management of urban rainwater and the management of the city's sewage system.

2 Materials and methods

2.1 Description of the study area

The present research was carried out in the city of Campina Grande, the seat of the homonymous county. The county is located in the interior of the state of Paraíba, more precisely in Agreste Paraibano, between the regions of the low and middle courses of the Paraíba River.

The Campina Grande macro-drainage system covers three important urban basins: the Bodocongó Creek Basin (B basin), the Piabas Creek Basin (C basin) and the Prado creek Basin (basin D), which is listed for the study. It covers the southern part of the city, partially or totally comprises 22 districts and is subdivided into 13 sub-basins (THMCG 2015).

The drainage canal inserted in the study area is known as the Prado canal, with sample collections from it. Figure 1 illustrates the study area of the present study.

2.2 Samples

For the accomplishment of this work, eight sampling points were chosen, in order to make a complete coverage of the macro-drainage system of the Prado Creek. Also, in Fig. 1, the distribution of the sampling points along the Prado canal was presented as well.

It should be noted that 5 of the 8 points are located in the canal in their artificial form (being 2 and 4 located in two of the main tributaries) and 3 points already in the canal in their natural form.

Samples for laboratory analysis were started in March and ended in October 2018, counting 30 campaigns in this period, with weekly collection frequency always occurring at 8 o'clock in the morning.

The procedures performed in the collection as well as the packing of the samples followed the standard recommended in the standard methods for the examination of water and wastewater (APHA 2012).

After the sampling, the samples were sent to the Laboratory of Sanitation of the Academic Unit of Civil Engineering - UFCG, for the immediate accomplishment of the analyzes.

2.3 Laboratory analysis

Physical–chemical and microbiological analyses of the following indicators were performed: dissolved oxygen (DO), biochemical oxygen demand (BOD_5), Chemical Oxygen Demand (COD), kjeldahl nitrogen (TKN), ammoniacal nitrogen (NH_3-N), total phosphorus (P-total) and thermotolerant coliforms (CTT). All the laboratory techniques used followed the indications expressed in APHA (2012).

It should be noted that the choice of these indicators was based on the fact that they gather relevant information on pollution in drainage waters.

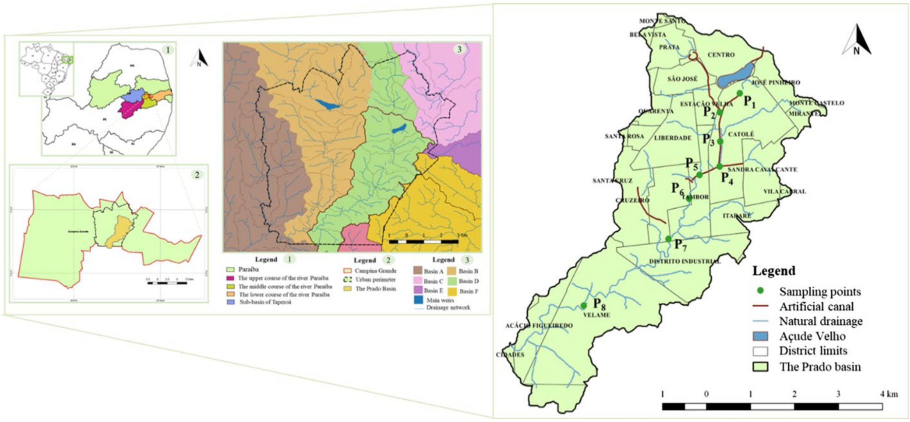

Fig. 1 Location of the study area

2.4 Statistical analysis

Data tabulation was performed using Excel spreadsheets in the Microsoft Office 2013 for Windows Package. For the tests of normality, descriptive statistics, boxplot graphs, analysis of variance (ANOVA) and Tukey test, we used the software Action Stat 3.5.

The ANOVA was also used to compare multiple averages by means of the Tukey test for the indicators (BOD_5, COD, NTK, ammoniacal nitrogen, total phosphorus, and CTT) in order to identify the differences between pairs of specific averages or in linear combinations of the averages.

2.5 Self-purification study

With the purpose of evaluating the assimilation capacity of the organic matter of the Prado canal and thus to verify the impacts resulting from the improper discharge of wastewater, a self-purification study is necessary and extremely relevant.

For this, the classic model of Streeter and Phelps (1925 apud Von Sperling 2014b) is generally used because of its conceptual simplicity and less need for parameters and input data. However, this model is only valid for strictly aerobic conditions, a condition that is opposite to that verified along the canal.

Therefore, was used the advanced modeling of dissolved oxygen under anaerobic conditions proposed by Gundelach and Castillo (1976), which is in Chapter 9 of the book Von Sperling (2014b).

Advanced DO modeling incorporates in its balance the OD consumption by nitrification, sedimentation of organic matter, diffuse loads without flow (sediment demand, photosynthesis, respiration, external loads) besides deoxygenation and atmospheric re-evaluation (already included in the classic model of Streeter and Phelps).

The development of the study was supported by Excel spreadsheets available for download at www.editoraufmg.com.br/sperling_vol07_2aEd.zip.

In the spreadsheet entitled Streeter with anaerobiosis contained all the equations necessary to simulate the behavior of the OD, BOD and nitrogen (ammoniacal and organic) attention should be paid to the particularities of the coefficients for each water body.

Equations 1–6 show the models expressed in differential equations used for the calculations of:

- Carbonic BDO:

$$\frac{\mathrm{d}L}{\mathrm{d}t} = -k_\mathrm{d} \cdot L - k_\mathrm{s} \cdot L + L_\mathrm{rd} \tag{1}$$

- OD Deficit:

$$\frac{\mathrm{d}D}{\mathrm{d}t} = -k_2 \cdot \left(C_\mathrm{s} - C\right) + k_\mathrm{d} \cdot L + S_\mathrm{d} - F + R + R_{O2\mathrm{amon}} \cdot (f_\mathrm{nitr} \cdot k_\mathrm{an}) \cdot N_\mathrm{amon} \tag{2}$$

- Dissolved oxygen:

$$\frac{\mathrm{d}C}{\mathrm{d}t} = k_2 \cdot \left(C_\mathrm{s} - C\right) - k_\mathrm{d} \cdot L - S_\mathrm{d} + F - R - R_{O2\mathrm{amon}} \cdot (f_\mathrm{nitr} \cdot k_\mathrm{an}) \cdot N_\mathrm{amon} \tag{3}$$

Table 1 Variables of OD, BOD and N models

Symbol	Description	Unit
L	Ultimate BOD concentration	(mg/L)
C	OD concentration	(mg/L)
D	The deficit of dissolved oxygen	(mg/L)
N_{org}	The concentration of organic nitrogen	(mg/L)
N_{amon}	The concentration of ammoniacal nitrogen	(mg/L)
t	Travel time	d

$$\text{Ou} \quad \text{OD} = C_{\text{s}} - D \tag{4}$$

- Organic Nitrogen:

$$\frac{\mathrm{d}N_{\text{org}}}{\mathrm{d}t} = -k_{\text{oa}} \cdot N_{\text{org}} \tag{5}$$

- Ammonia:

$$\frac{\mathrm{d}N_{\text{amon}}}{\mathrm{d}t} = k_{\text{oa}} \cdot N_{\text{org}} - (f_{\text{nitr}} \cdot k_{\text{an}}) \cdot N_{\text{amon}} \tag{6}$$

It is noteworthy that under anaerobic conditions, the BODu calculations were performed by means of Eq. 7, and the following return conditions to aerobiosis are always verified:

$$\frac{\mathrm{d}L}{\mathrm{d}t} = -k_2 \cdot C_{\text{s}} \tag{7}$$

- If $L \leq K_2\ C_{\text{s}}/K_{\text{d}}$—return to aerobiosis
- If $L > K_2\ C_{\text{s}}/K_{\text{d}}$—permanence in anaerobiosis

Tables 1 and 2 present a synthesis of the variables, coefficients and other input data related to the OD, BOD and nitrogen models mentioned above, which can be found in Von Sperling (2014b).

3 Results and discussion

The values determined in the analysis of the indicators (BOD$_5$, COD, NTK, N-NH$_3$, Total phosphorus, and CTT) are presented in Fig. 2. These were organized in boxplot graphs for better visualization of the distribution and dispersion of data; in addition, this graphical tool allows a comparative analysis between the data set of each point.

It should be noted that, in accordance with the guidelines for the State System for the Licensing of Pollution Activities (SELAP) in 1988, the waters of the Paraíba river basin (Guideline 205), carried out by SUDEMA of the Prado Creek, according to the prevailing uses, are classified in class 3.

As the aforementioned guideline does not present individual limits for indicators that characterize water quality, class 3 of National Environment Council Resolution 357/2005,

Table 2 Coefficients of OD, BOD and N models and other input data

Symbol	Description	Unit
k_d	BOD decomposition coefficient	(d^{-1})
k_s	Coefficient of removal by sedimentation	(d^{-1})
k_r	Decomposition and sedimentation	(d^{-1})
L_{rd}	Diffuse BOD input rate in net mass	mgBDO/L d
k_2	Re-evaluation coefficient	(d^{-1})
k_{oa}	Coefficient of conversion of organic nitrogen to ammonia	(d^{-1})
k_{an}	Coefficient of conversion of ammonia to nitrate	(d^{-1})
f_{nitr}	Correction factor of k_{an} as a function of OD	–
Ro_{2amon}	Relation between the oxygen consumed by each unit of oxidized ammonia	mgO_2/mgN_{amon}
S_d	Sediment oxygen demand	mgO_2/L d
F	Rate of oxygen production by photosynthesis by algae and macrophytes	mgO_2/L d
R	Rate of oxygen uptake by algae and macrophyte respiration	mgO_2/L d
C_s	OD saturation concentration	(mg/L)

which establishes the same preponderant uses of Guideline 201, will be considered for verification compliance with the limits of each indicator.

From the boxplot graphs, different behaviors between the sampling points are observed. There is a minimum BOD_5 at point 1 for 12 mg/L and a maximum value of 576 mg/L at point 4.

With the exception of point 1, located upstream of all sewage inputs, it can be seen that the drainage waters of the Prado canal show a range of average concentrations of BOD_5 typical of sanitary sewage, although varying from concentrations considered to be weak (P_5, P_6, P_7, and P_8), medium (P_2 and P_3) and strong (P_4). These concentrations were based on those described by Jordão and Pessôa (2017).

Anny et al. (2017) evaluated the pollution of surface waters in urban and industrial areas in Bangladesh, represented by Karnapara canal receiving textiles, domestic wastewater and runoff from nearby farmland, and obtained an average of BOD_5 of 92.22 mg/L. Such value is close to those verified in the points located in the canal already in their natural form which are 6, 7 and 8.

Freire (2014) studied the water quality of the Piabas canal, which is part of another basin that contributed to the Campina Grande macro-drainage system and found a mean BOD_5 (mean value 158 mg/L) lower than that found in the study, indicating a higher organic matter load in the Prado canal. However, it should be noted that the water depth of the Piabas canal is considerably higher than that of the canal under study, and thus, the dilution of this organic load is favored.

The highest values for this indicator are found in points 2 and 4. These are located in the two main tributaries that flow into the main canal and contribute significantly to the degradation of water quality. These points, along with 3, present the largest interquartile ranges, resulting from the difference between the values of the third quartile and those of the first quartile, indicating a greater variability of the data set when compared to the other points, and that can be explained in the premise that they receive the contributions of sewage with the highest pollutant loads.

Analyzing the mean values of BOD_5 of each point studied, it is observed that all exceed the limit of 10 mg/L, established in National Environment Council Resolution 357/2005.

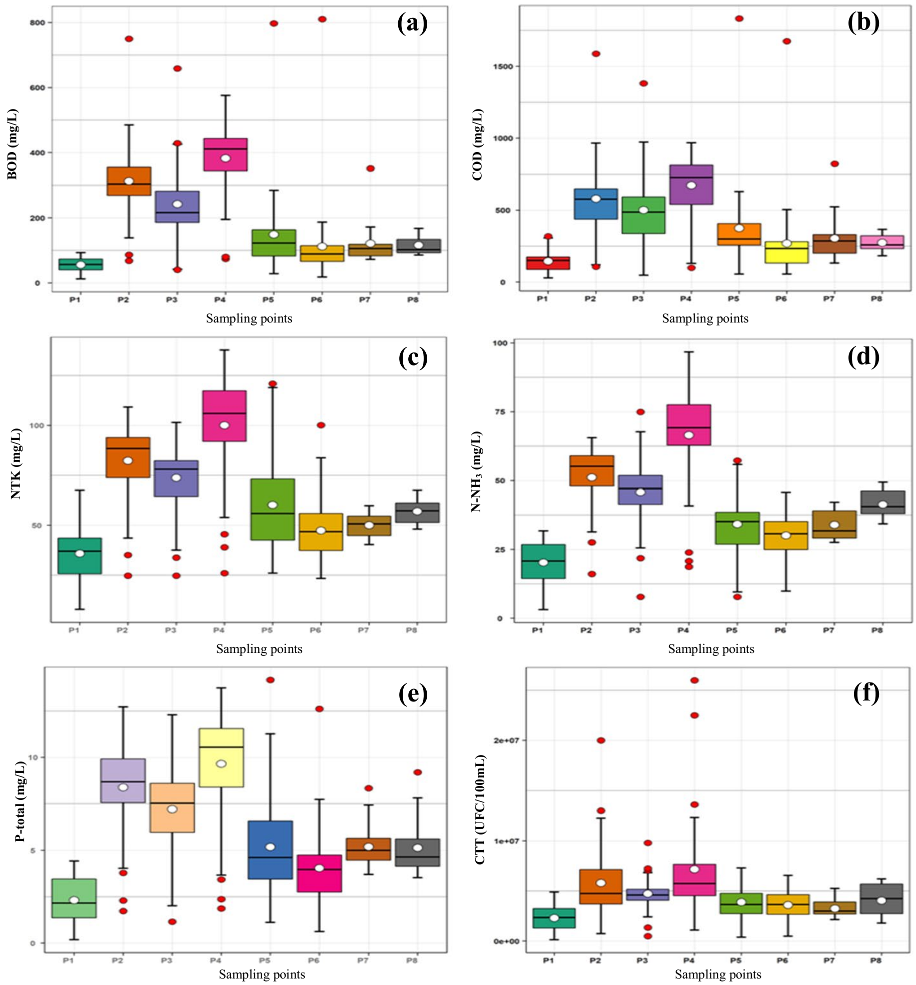

Fig. 2 Boxplots of BOD_5 (**a**), COD (**b**), NTK (**c**), $N\text{-}NH_3$ (**d**), P-total (**e**) and CTT (**f**)

It was also observed the presence of outliers (red circles in the boxplot graph), which are data that differ drastically from all others, that is, values that are distanced from the reality of the data set and that can strongly affect the results.

However, all the outliers presented in the boxplot are justified. These are derived from atypical situations (moderate and strong intensity precipitation, canal cleaning, vegetation weeding near the canal) that occurred along and near the canal, which modified the quality of water on that specific day.

Regarding the COD indicator, it was found that similar to what happened with BOD_5, a minimum value of 28 mg/L COD was found in point 1 and a maximum value of 964 mg/L in point 4.

When evaluating their average band's concentrations, it was observed that, except for the point 1, the others are characterized by exhibiting typical concentrations of sewage ranging concentrations considered weak (P_5, P_6, P_7, and P_8) and means (P_2, P_3, and P_4).

The highest values for this indicator are found in points 2, 3 and 4 (867, 792 and 968 mg/L, respectively).

These points present the largest interquartile ranges as well as the largest amplitudes. This variability is due to releases of domestic sewage, intermittently, either in the rainwater drainage system or directly in the water body.

Henriques (2014) found values of COD at 115, 564 and 626 mg/L, which were very close to the one observed in this study, evaluating areas close to some points of the survey (P_1, P_2, and P_4). Torquato (2017) evaluated the water quality of Açude Velho and verified, in the immediate vicinity of the spillway, an average concentration of COD 107 mg/L. It should be noted that point 1 receives water from this spillway, and in this study, a value close to the above-mentioned one was found.

Total nitrogen corresponds to all the nitrogen fractions found in the waters under the forms of organic nitrogen, ammoniacal, nitrite and nitrate, which are associated with the age of pollution. These nitrogen compounds in the water are the result of discharges of domestic and industrial effluents and fertilizers used in agricultural crops, which are transported to the drainage network by surface runoff (Von Sperling 2014a).

The average concentrations of NTK at the points studied show that these are typical ranges of sanitary sewage, varying between concentrations considered to be weak (P_1, P_5, P_6, P_7, and P_8), mean (P_3) and strong (P_2 and P_4).

There is a minimum value of 7.8 mg N/L at point 1 and a maximum value of 137.9 mg N/L at point 4. The highest values for this indicator are found in points 2 and 4 because they are located at points that receive the highest contribution of domestic dumps with a high load of nutrients.

The largest interquartile range, as well as the greatest amplitude, is verified in point 5, disregarding the previous indicators that always focused on points 2, 3 and 4. This fact can be justified by the continuous launching of wastewater, by means of two underground pipelines; at this point in the study that leads to the great variability in the concentration of the indicator in question, however, was also observed a downstream stabilization due to the biochemical conversion processes.

Von Sperling (2014b) states that in a watercourse, determining the predominant form of nitrogen can provide indications about the stage of pollution caused by some upstream sewage. If this pollution is recent, the nitrogen will be mainly in the forms of organic or ammoniacal nitrogen and, if old, basically in the form of nitrate, provided that enough dissolved oxygen is available in the medium in question to allow nitrification.

Initially, average concentrations of NH_3 and high bands observed, with typical sewage, ranging from mean concentrations considered (P_1, P_3, P_5, P_6, P_7, and P_8) to strong (P_2 and P_4).

At all points, the limit of 5.6 mg/L to $7.5 < \mathrm{pH} \leq 8.0$, as established by National Environment Council Resolution 357/2005 for water bodies classified in class 3, is exceeded with a large margin, in the case of the present study. As an aggravating circumstance, even the effluent release standard established in National Environment Council Resolution 430/2011, which is at most 20.0 mg/L of N-NH_3, has also been exceeded, evidencing the large volume of domestic releases that are released daily.

It was observed that in all the points the ammoniacal fraction excelled to the organic fraction. It is noted that most of the NTK in the domestic sewage has a physiological origin (dominated by ammonia) and therefore this prevalence.

With this qualitative evaluation, there is an indicative of the areas that need a more incisive inspection, with respect to illegal connections in the drainage canals; in addition, they contribute in a decisive way in the planning of the actions to be implemented for improvement in the local health.

When analyzing the average concentrations of total phosphorus in the drainage waters of the Prado canal, it is verified that these are typical ranges of sanitary sewage, varying between concentrations considered to be weak (P_1, P_2, P_3, P_5, P_6, P_7, and P_8) and mean (P_4).

There is a minimum value of 0.2 mg/L of P-total in point 1 and a maximum value of 13.7 mg/L in point 4. Similarly, to total nitrogen, the highest values for this indicator are found in points 2 and 4, because they are located at points that receive the highest contribution of domestic dumps provided with a high nutrient load.

Anny et al. (2017) evaluating the pollution of the waters Karnapara canal in Bangladesh found mean values of 1.22 mg/L total phosphorus which are below the values observed in the present study.

In large part, high amplitudes and high interquartile ranges are observed, which can be justified by uncontrolled environmental factors, such as rainfall, effluent flows, as well as the cycle of this element inside the water body, which depends on pH, depth of the water column, temperature, presence of some metals that accelerate the sedimentation process, and other characteristics of the liquid mass.

When the degree of atrophy of the Prado canal is evaluated, according to the bands presented by Von Sperling (2014b), it is verified that it is classified as hypereutrophic because it presents average values in the studied points way above 0.1 mgP/L.

It should be noted that all the points extrapolate, with a large margin, the total P-limits established for the 3 types of environment (lentic, intermediate and lotic—considering the 3 situations along the canal) in National Environment Council Resolution 357/2005 for water bodies classified in class 3.

The average concentrations of thermotolerant coliforms were around 10^6. Jordão and Pessôa (2017) state that *in nature* domestic sewage has values between 10^6 and 10^9 (CFU/100 mL), that is, after all the indicators evaluated, the association between the quality of the waters of the macro-drainage system and the discharge of sanitary sewage.

Henriques (2014) evaluated the distribution of fecal contamination along the Prado canal and found mean concentrations of CTT in the order of 10^6 to 10^7 CFU/100 mL.

Caminha (2014), when analyzing the degradation of the water quality of urban subbasins of Campina Grande, verified average concentrations of CTT in the order of 10^6 CFU/100 mL. Freire (2014) studied the Piabas canal, located in another important urban basin of Campina Grande, and also found average concentrations in the order of 10^6 CFU/mL.

The evaluation of the physical–chemical and microbiological indicators proves to fecal contamination in the drainage waters of Campina Grande demonstrating that in these waters the prevalence is of domestic sewage. This contamination culminates in risks to public health due to the increase in the possibility of transmission of infectious diseases, with the potential to cause death to the riverside inhabitants to these water bodies. In addition, these inhabitants are conditioned to low quality of life, due to the unpleasant odors, the proliferation of arthropods and rodents and the lack of local health which results in reducing life expectancy as well as losses in the development of children.

In this way, to carry out the identification of the discharge of sewage sources for further interruption, deploy complete systems (from the collection network to treatment) sewage periodically inspect illegal connections, through joint actions between the government and companies sanitation, promote environmental education actions to sensitize the population about the gains and consequences of appropriate management of solid and liquid waste are measures that can contribute to the solution of this environmental liability.

3.1 Analysis of variance (ANOVA)

For multiple comparisons of averages, the Tukey test was applied to all the indicators in order to identify where the significant differences occurred and thus get an overview of priorities for action to the vicinity of the sampling points.

Figure 3a graphically illustrates the statistical equality, considering a significance level of 5%, of the BOD_5 averages at points P_5, P_6, P_7 and P_8, as well as at which points the largest significant differences occurred. It should be noted that the further away from the red dashed line, the greater the significant statistical differences.

When the COD indicator was evaluated, four groups of statistically different averages were found. It was observed that, unlike the BOD_5 indicator, the averages of P_2 and P_3 are statistically the same (variation from 470 to 546 mg/L). The averages of P_1, P_6, P_7 and P_8 (range of 145–270 mg/L) are also statistically the same. The behavior of the point averages, in relation to statistical differences, is shown in Fig. 3b.

When examining the behavior of the averages along the points referring to the NTK data, it is verified that the averages of P_1, P_6 and P_7 (variation of 35.9–50.0 mg/L) are

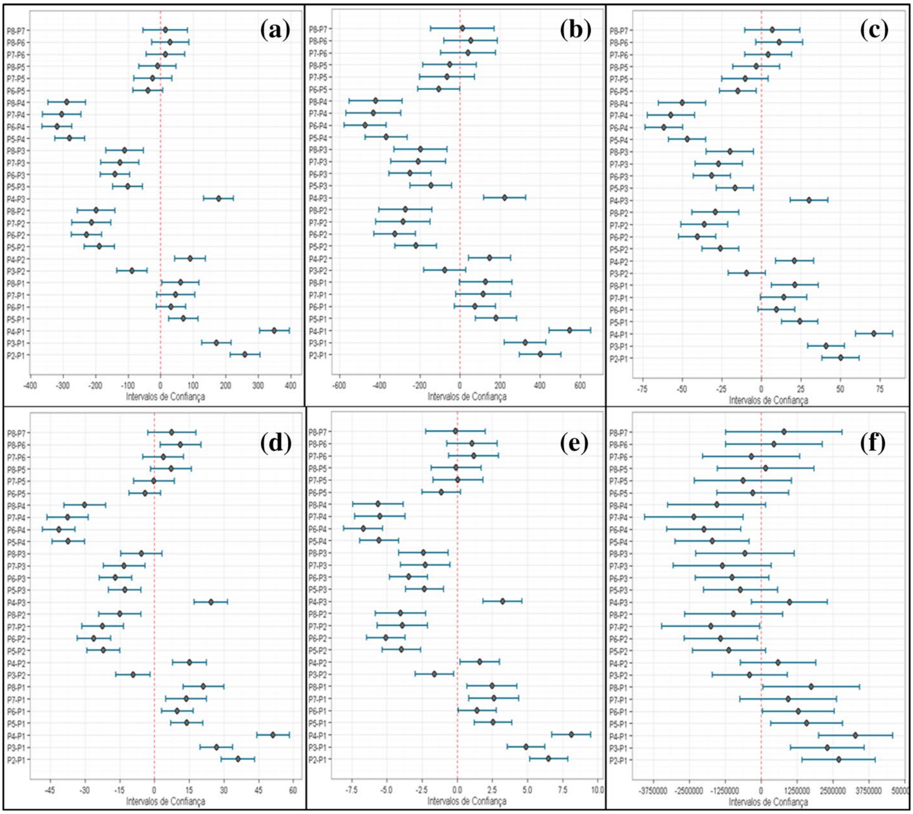

Fig. 3 Tukey test for data analysis: BOD_5 (**a**), COD (**b**), NTK (**c**), N-NH_3 (**d**), P-total (**e**) and CTT (**f**)

statistically the same; similar to the COD indicator, the averages of points 2 and 3 and points 5, 7 and 8 are also equal. Figure 3c shows graphically where statistical equality, as well as differences, occur.

The ammonia nitrogen data, unlike the others, presented more groups of statistically different averages. This higher number of groups may be due to the biological oxidation processes suffered by the ammonia and, as a consequence, there is a greater variation from one point to another. In general, only points 5, 6 and 7 express statistically equal averages (variation from 30.1 to 34.2 mg/L), and the nuances of variation of occurrences of significant differences of averages are shown in Fig. 3d.

When analyzing the behavior of the points for total phosphorus, it was observed that this occurred in a way analogous to the BOD_5 indicator, being the occurrences of significant differences of means presented in Fig. 3e.

When analyzing the grouping of CTT, it is verified that, unlike the other indicators, most of the averages of the points studied are statistically the same. This equality is found in points 3, 5, 6, 7 and 8 and illustrated in Fig. 3f.

It is noteworthy that, from this analysis, we observed the order of priority actions in sampling points, as well as verify the points that can be adopted the same measures because they present similar characteristics to each other.

In general, the P2 and P4 (tributaries of the canal) were those with the highest average pollution indicators making necessary the adoption of short-term measures in these surroundings, so that is mitigated all this pollution load which flows into the Prado canal. The quality of water in points 3 and 5 will be considerably enhanced as soon as the actions in points 2 and 4 are carried out. In relation to points 1, 6, 7 and 8, measures can be taken in the medium term due to lower values of organic load and of nutrients that were found as well as the dilution factor in these points (with the exception of point 1) that can be considered.

It is emphasized that the points 1 through 5, the water depth is not significant (> 10 cm) and thereby diluting the wastewater inflow is practically nonexistent.

3.2 Self-purification capacity of Prado Creek

The results concerning the behavior of OD and BOD_u along the Prado basin, in front of all wastewater discharge, are presented in Fig. 4. It is verified that in 68% of the studied section (10.74 km) the conditions are of anaerobiosis.

The Prado stream begins shortly after the extra water from the Açude Velho water, presenting OD and initial BOD_u of 5.6 mg/L and 15 mg/L, respectively.

At approximately 390 m, a small increase in BOD_u (about 56 mg/L) is observed, resulting in oxygen consumption and its consequent decrease. This increase in BOD_u can be due to the launching of wastewater from the children's park and a small portion of the Catolé neighborhood to the interior of the canal.

We highlight the stretches that flow from the tributaries represented by points 2 and 4, where the highest concentrations of BOD_u and imminent depletion of all oxygen are verified. On reaching 5, an increase in OD concentration due to aeration in the water caused by the turbulent reception of a continuous and significant quantitative flow of wastewater from Jardim Paulistano was observed.

From point 6 (where the canal becomes its natural form), a tendency of the river to use its assimilation capacity of the organic matter is verified; however, it is always impaired

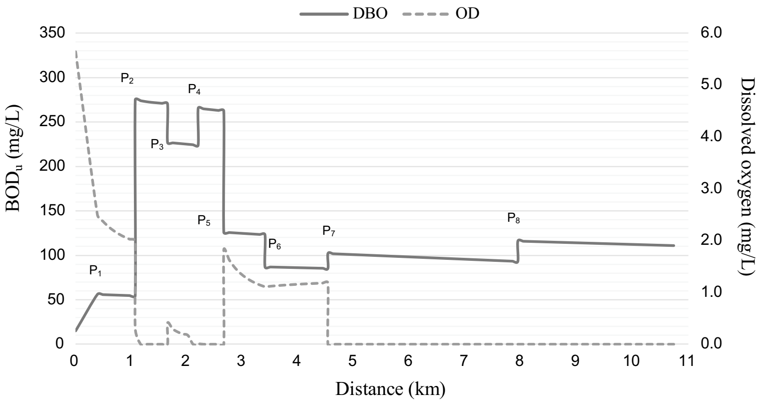

Fig. 4 Profiles of OD and BOD_u along the Prado creek

due to the occasional releases of effluents that interrupt this attempt of reestablishment equilibrium in the aquatic environment.

It is worth noting that in all the studied section OD and BOD_u concentrations did not meet the values established in National Environment Council Resolution 357 for water bodies classified in class 3, which is OD higher than 4 mg/L and BOD lower than 10 mg/L.

When the water quality modeling of the Prado stream was continued, it was found that, following the low speed and high depth conditions (which do not favor the re-evaluation) of the last section, the dissolved oxygen is only reestablished 24 km after the end of study, if there are no launches up to this distance.

However, at the end of this stretch, the Prado stream flows into the Bodocongó River, which then flows (about 48 km later) into the Paraíba River, a tributary of the main surface reservoirs of the Paraíba River basin. Therefore, it would be necessary to know the quality data of the Rio Bodocongó to model the mixture and the possible impacts in the Paraíba River, which may be negative or even positive.

In aerobic conditions, the main mechanisms of oxygen consumption and production are deoxygenation and atmospheric re-reaction, respectively. As it was verified that most of the creek is under anaerobic conditions, other processes must be included in the dissolved oxygen balance, as for example the nitrification that demands oxygen to oxidize the ammonia to nitrite and this to nitrate.

For this, the results concerning the behavior of the nitrogen fractions that are commonly found in raw sewage (ammoniacal and organic nitrogen) are presented in Fig. 5.

Significantly higher values of these nitrogen fractions were observed in the Prado stream waters, indicating the occurrence of domestic sewage discharge, in addition to inferring a recent stage of pollution.

Knowing the pollution content in the macro-drainage system of the Prado urban basin as well as the damage that this degradation causes to the health of the residents, the study leads us to the following reflections:

The socioeconomic and environmental point of view is more feasible to carry out the mapping of illegal connections to consequential interruptions, and later interconnections to a complete and efficient system of sewage or by the current reality allow the continuation of this release inappropriate and promote the treatment of this water wastewater only downstream, already in the exutory of the basin?

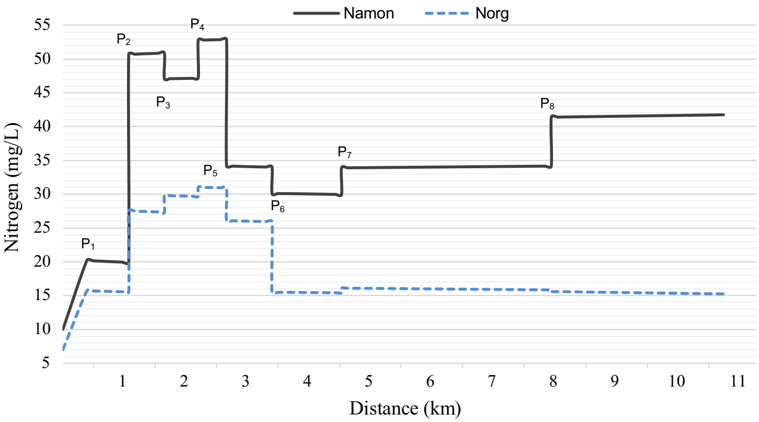

Fig. 5 Profiles of nitrogen forms along the Prado creek

It was verified in the Municipal Plan of Basic Sanitation of Campina Grande (THMCG 2015) that the great majority of the neighborhoods that compose the urban basin Prado watershed are attended with sewage collection networks, as well as an interceptor in your surroundings. Confirming the above, it was observed that according to the National Sanitation Information System (National Sanitation Information System 2016), the rate of sewage collection in the municipality of Campina Grande is 99.89%, that is, there is a sanitary sewage system (SSS) that needs better management to make it efficient.

In this sense, it is evaluated that many residents pay for sewage services; however, these only contemplate the collection and transport of the sewage to a receiving body, be it a drainage canal or even urban dams and, thus, the treatment of sewage has gaps. Therefore, from the social and environmental point of view, the recommendation is that specific interventions be carried out in the clandestine connections of domestic sewage and in the other hazards listed in the risk assessment.

From the economic point of view, two aspects can be analyzed: The first refers to the downstream treatment that costs less investment, considering that the costs of network deployment and connections within an SSS are the most significant (around 74%), and these would be absent; in addition, in the exutory of the basin already started the process of depuration which possibly would entail a reduction of the concentrations of organic matter and nutrients, thus facilitating treatment processes.

The second aspect is focused on the health benefits that interventions can provide. The risk assessment was presented to diseases which residents are exposed to, and when assessing that R $ 1.00 invested in sanitation there is a savings of $ 4.00 on health (WHO World Health Organization 2014), it is clear that, beyond the gains to the health of residents, the final economic balance may be also lower.

It should also be noted that the existence of the collector network and the interceptor is already a great economic advantage to the SES, and in some cases, only some extensions or restructuring in certain points may be lacking. It is up to managers to consider all the possibilities, always with priority the welfare of the residents and the maintenance of the environment.

4 Conclusion

From the execution of the present work, it was possible to evaluate the dynamics of pollution in the macro-drainage system of the Prado urban basin. High organic and nutrient loads were found as well as high orders of the microbiological indicator in most of the sample points.

It was found that the water drained by the river basin has typical characteristics of sewage with high pollution potential. Continuous release of domestic sewage was observed during the entire period of the collection campaigns, besides inadequate disposal of solid waste, mainly in the two main tributaries of the canal. This scenario implies a number of risks to public health, especially for the populations bordering this canal.

The points that presented critical quality were: 2 and 4, these being the places with priorities for interventions in the short term. The results of this qualitative evaluation should support studies that aim to mitigate this polluting burden.

All quality indicators evaluated in the study did not meet, at any time, the values established in National Environment Council Resolution 357/2005 for water bodies classified in class 3.

In view of the dissolved oxygen profile along the canal, it was verified that the self-depuration capacity of the canal was largely exceeded and that the equilibrium reestablishment of the aquatic environment (return of the dissolved oxygen) will only occur after 24 km of the end of the studied section if not occurs until said distance.

Acknowledgements The National Council for Scientific and Technological Development (CNPq) for granting financial aid to support the conduct of research.

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