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Using the pollutant load concept to assess water quality
in an urban river: the case of Carahá River (Lages, Brazil)

Using the pollutant load concept to assess water quality in an urban river: the case of Carahá River (Lages, Brazil)

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ABSTRACT

The objective of this study was to evaluate the water quality of Carahá River in Lages (Brazil), using the concept of pollutant load and comparing the results with the water quality index. Thirteen points along the river were selected and eight collections were carried out over a period of 16 months. The parameters analysed were those required for the calculation of the water quality index (WQI). Flow measurements were also carried out, which enabled the calculation of the polluting load. The results showed that the WQI score ranges between 24.95 at the source and peaks at 40 at the outlet. The water classification, therefore, ranges from "very bad" to "bad". The calculation of the pollutant load showed a constant disposal of contaminants into the river, which demonstrates that the quality of the water is continuously degraded. This information could not be obtained by analysing only the WQI, which presented a nearly constant quality at point 4 and beyond. The use of the calculation of pollutant load for Carahá River is, therefore, a tool for assessment of pollution that can provide more appropriate information for the water resources management.

Keywords: flow, pollutant load, urban river, water quality index.

Avaliação da qualidade da água de um rio urbano utilizando o conceito de carga de poluentes: o caso do Rio Carahá (Lages, Brazil)

RESUMO

O objetivo deste trabalho foi avaliar a qualidade da água do Rio Carahá no município de Lages (Brasil), utilizando o conceito de carga de poluentes e comparar a representação dos resultados com aquela expressa por meio do índice de qualidade da água. Para este estudo foram selecionados 13 pontos ao longo da calha do rio e realizadas 8 coletas durante o período de 16 meses. As análises realizadas envolveram os parâmetros necessários para o cálculo do índice de qualidade da água (IQA). Foram ainda realizadas medições de vazão, o que possibilitaram a realização do cálculo da carga poluidora. Os resultados do IQA mostraram que a pontuação varia entre 24,95 para a nascente, chegando a 40 no exutório da bacia, classificando a água de "péssima" a "ruim". O cálculo da carga orgânica demonstrou uma adição constante de poluentes ao rio, o que demonstra que a qualidade da água é continuamente degradada. Esta informação

não foi possível de ser obtida analisando-se somente o IQA, o qual apresentou uma qualidade praticamente constante a partir do ponto 4. Desta forma, para o rio Carahá, a utilização do cálculo da carga constitui-se em uma ferramenta de avaliação da poluição que pode trazer informações mais adequadas para a gestão de deste recurso hídrico.

Palavras-chave: carga poluidora, índice de qualidade da água, rio urbano, vazão.

1. INTRODUCTION

One of the most widely used tools for the assessment of water quality in rivers is the water quality index (WQI). This index was developed from a mathematical relationship that transforms the result of various analyses of physical, chemical and microbiological parameters into a single number. This simplifies the quality evaluation of the fresh waters (Maane-Messai et al., 2010). This index is widely accepted, as it plays an important role in the process of translation, as a tool used to communicate water quality (Bhatti and Latif, 2011). The use of the WQI in studies of water quality has been widely addressed over a long period. As an example of preliminary work, Egborge and Benka-Coker (1986) carried out their studies in the Warri River, Nigeria. More recent studies, such as the Hou et al. (2016) study of the Yellow River and Sun et al. (2016) of the Courtyard River, both in China, and Abdel-Satar et al. (2017) study of the Nile River in Egypt, highlight that WQI is still a useful tool for water quality assessment.

Although the use of the WQI has been widely accepted in investigations that involve the assessment of the water quality of rivers, one issue that needs to be raised is, to what extent will flow measurement affect the water quality evaluation? In this respect, an alternative way to evaluate the effects of pollution in rivers is the use of the concept of pollutants load. However, the concept of the load has traditionally been used for the design of effluent treatment systems and is not commonly used in studies on water quality in rivers. The volumetric organic load, for example, is a fundamental parameter for the design of biological reactors for treating sewage and industrial effluents (Metcalf and Eddy, 2013). For the monitoring of water resources, the use of more widespread pollutant load is related to the calculation of the mass of suspended solids transported by water. This measure is an important indicator of soil loss and also the basis for the design and control of dams (Richards, 1998). According to this author, the knowledge of a load of suspended solids has a greater significance when compared to the concentration of these species.

Many researchers have addressed this issue in a similar manner. The following studies are some examples of investigations that were carried out: Ntengwe (2006) studied the Kitwe Stream in Zambia. The author investigated the levels of pollution, physical chemistry, biochemistry and the load of BOD_5, phosphorus, nitrate, sulphate and suspended solids. Zhang et al. (2012) studied the pollution of Lake Taihu in China. Parameters such as chemical oxygen demand (COD), ammonia, total nitrogen and total phosphorus were evaluated in terms of the pollutant load. Wang et al. (2013) used the concept of load to evaluate the runoff of pollutants due to various land uses and occupation in Chongqing in China. The application of the concept of the load was used to check which activity has more intensely influenced the pollution of waters in that locality. Recently, Brodie et al. (2017) studied strategies to prioritize investments in pollution control on the Great Barrier Reef in Australia. The authors used the concept of load to evaluate which watersheds had the greatest influence on the pollution of reefs and used it to improve the effectiveness of programs for environmental protection. Finally, Li et al. (2019) applied the pollutant load concept to study benzene series in an urban environment.

Based on these studies, we can observe that the pollutant load concept has been considered by many authors as a tool for evaluating the impact of pollution in rivers. In addition, the Carahá

River in the municipality of Lages (Brazil) has not been studied, despite the investigations carried out by Antunes et al. (2014). A gap therefore exists in the literature which must be filled by additional research on the Carahá River, so as to obtain useful data for public policy and environmental management. In this context, the objective of this study was to compare the water quality index to the concept of the load in a specific river and evaluate which methodology provides more substantial information.

2. MATERIALS AND METHODS

2.1. Sample collection location

The study was conducted along the Carahá River, in the municipality of Lages, located in the south of Brazil. The watershed of the Carahá River is at an average altitude of 988.32 m. It has a surface area of 30.17 km², about 58% of which is an urban area. In the basin, there are approximately forty thousand buildings, with an estimated population of 120,000 inhabitants. The watershed is roughly circular in shape, although its Shape Factor equals 0.59 and its Circularity of 1.89 indicates otherwise. This explains why the main channel of the basin is quite extensive in relation to its area, from where these coefficients derive. Although the average slope of the basin equals 7%, indicating a smoothly undulating relief, the Carahá River basin has mountainous relief at its headwaters (the total altimetric range of the basin is 240.00 m in a total length of 6.8 km). The longest flow path of the watershed is 9.7 km, with the average sinuosity of 1.66 km km^{-1}, which makes this channel a little winding, especially in the reach where it is channelled. The watershed of the Carahá River, therefore, is prone to generate large volumes of surface runoff from intense rainfall, which commonly cause flood disasters. The urban predominance also explains the possibility of finding high rates of pollution in the drainage channels.

The samples were taken every two months over a period of 16 months. Thirteen sampling points were selected, distributed to represent the various sub-watersheds according to Otto Pfafstetter, resulting in an approximate distance of 500 meters from one point to another as shown in Figure 1.

2.2. Analytical methods

The samplings were carried out in accordance with the procedures recommended by the standard guidelines for the collection and preservation of samples (American Public Health Association, 2005). The assessment of water quality was carried out according to physical, chemical and microbiological parameters. The analytical determinations were conducted in accordance with the methodologies described in the "Standard Methods for the Examination of Water and Wastewater" - SM (American Public Health Association, 2005). The parameters analysed were: thermotolerant coliforms (Method SM 9222 (D), biochemical oxygen demand – BOD5 (SM 5210 Method B), phosphorus (Method SM 4500-P (B and C), nitrite (SM 4500-NO2- B), Total Kjeldahl Nitrogen - TKN (SM 4500-Norg C), dissolved oxygen (SM 4500-G), pH (SM 4500-H+ B), total dissolved solids - TDS (SM 2540 C), total suspended solids - TSS (SM 2540 (D) and temperature (SM 2550). The concentration of nitrate was determined by the method DIN (Deutsches Institut für Normung) 38405-9 (Deutsches Institut für Normung, 1979). The determination of total solids was computed by adding up the measures of total dissolved and suspended solids. The total nitrogen (TN) was calculated as the sum of TKN, nitrate and nitrite.

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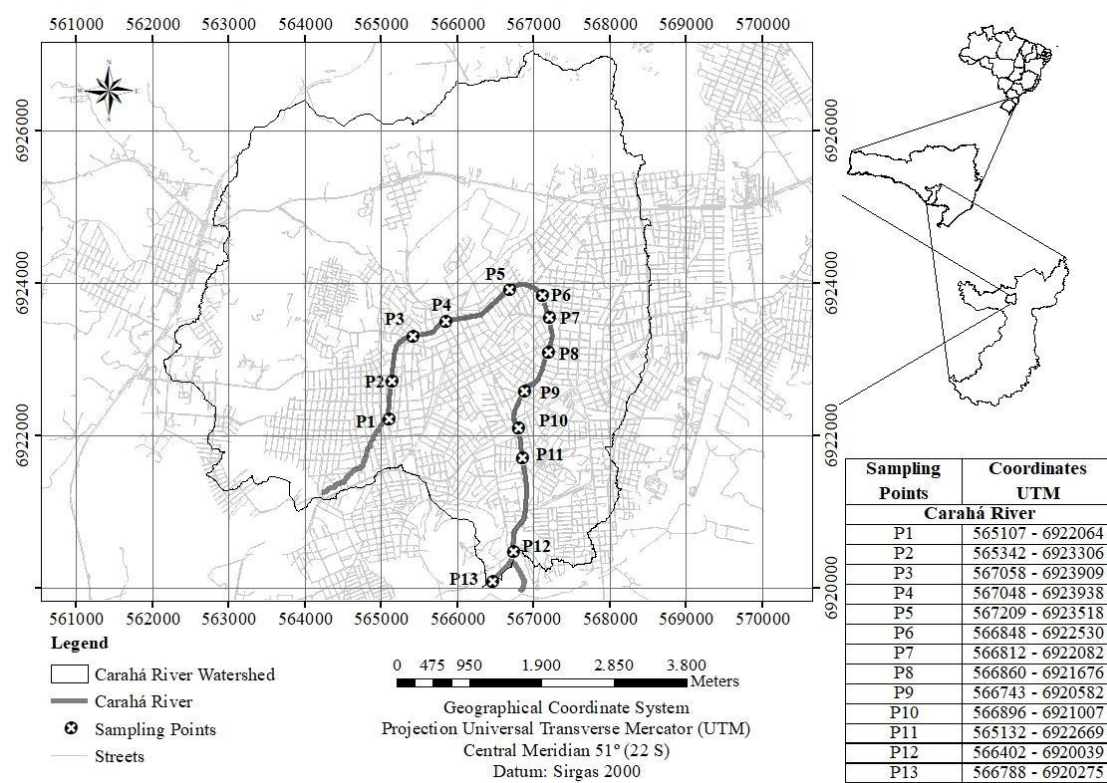
Figure 1. Map of Carahá River basin with the sampling points.

2.3. Water quality index (WQI)

The WQI was calculated by the weighted product of the scores attributed to each parameter of water quality mentioned above. The scores are assigned according to pre-established curves (Equation 1) (Ott, 1978).

$$IQA_{NSF} = \prod_{i=1}^{n} q_i^{w_i} \qquad (1)$$

Where:

IQA is the water quality index (ranging from 0 to 100);

q_i is the score of parameter i, obtained by the specific curve;

w_i: weight assigned to the parameter in function of its importance in quality (ranging from 0 to 1).

The weights assigned to each parameter are the following (Ott, 1978): dissolved oxygen (0.17), thermotolerant coliforms (0.15), pH (0.12), biochemical oxygen demand (0.10), phosphorus (0.10), temperature (0.10), total nitrogen (0.10), turbidity (0.08) and total solids (0.08). Ott (1978) suggests that the quality of water is expressed according to the following ranges of scores: very bad (0 to 25), bad (26 to 50), medium (51 to 70), good (71 to 90) and excellent (91 to 100).

2.4. Flow measurement and calculation of Load

With regard to the flow measurement, this was performed in periods preceded by at least 72 hours with no precipitation. According to Padilha (2017), the time of concentration of the basin of the River Carahá is 4.73 hours. Considering the unitary hydrogram, the base time of the runoff in this basin corresponds to 39.6 hours, which implies that the measurements were

performed approximately 32 hours after the end of runoff from rain effective. The measurements were carried out on three different days.

For this activity, a water flow meter (OTT Hydromet) was used at sampling points 1 to 12. First, the water velocity and depth was measured at many points along the margins. Then, the water flow was determined by multiplying the average velocity of the channel by the cross-sectional area of flow. The measurement of the average velocity was performed at 60% below the water surface, according to guidelines suggested by Azevedo Netto et al. (1998).

The flow rate at point 13 was measured using an ADCP sensor (RiverRay), which communicates with WinRiver II software (Teledyne RD Instruments, 2016). The Q-boat 1800P (The Oceanscience Group, 2011) was used as a platform to drive the ADCP sensor in channel cross-section profiling.

Finally, after the determination of the concentration and flow data, it was possible to perform the calculation of pollutant load *F* according to Equation 2.

$$F = Q * C \tag{2}$$

Where:

F is the load (g h^{-1} or Kg h^{-1})

Q is the flow rate (L h^{-1})

C is the concentration (g L^{-1} or Kg L^{-1})

3. RESULTS AND DISCUSSION

3.1. Water quality index

The results of the WQI showed that water quality at point 1 is classified as "very bad" and at points 2 to 13 as "bad" (Table 1). Overall, the scores were below 40, which shows that the land use and occupation on this watershed likely affect the water quality. Curiously, even the point at the source (Point 1) is strongly impacted mainly by domestic sewage disposal. As this point presents the lowest water flow, there is a minimal effect of dilution, and consequently the WQI was on average 24.89, classifying the water at this point as "very bad". The municipality of Lages treats approximately 20% of all sewage, which may explain the predominance of water of "very poor" and "poor" quality. Among various types of environments and terrestrial landscapes, the urban rivers are the most used, occupied, modified, degraded, subjugated, and lastly, denied. In fact, there is a broad lack of environmental awareness from the society that inhabits its area. This is a problem which affects almost all developing countries.

Other authors studied several urban rivers and the obtained scores for the WQI are frequently similar. Souza et al. (2007), studied the Sal River in Sergipe, Brazil and classified its water as "very bad". Pontes et al. (2012) obtained a classification of "bad" to "good" for the Banguelo River, in the region of Contagem in Belo Horizonte, Brazil. In the study conducted by Sharma et al. (2014), the authors found that the Ganges River in Allahabad, India, was classified as "bad". Fia et al. (2015) studied the water body named "Ribeirão Vermelho" in Lavras, Brazil, and they obtained scores which classified it as "bad" to "medium".

Table 1 illustrates that WQI increases in the downstream direction from point 1 to 4 and it remains somewhat constant until the mouth. These results could probably be associated with the dilution effects along the river, and thus do not necessarily indicate an improvement of the water quality. This limitation is actually due to the WQI being calculated only by concentration measurements. This means that the impact of the water flow is not considered (Hoseinzadeh et al., 2015).

Table 1. Average measurement results for parameters.

Parameter	Points												
	1	2	3	4	5	6	7	8	9	10	11	12	13
DO (mg L^{-1})	3.08	2.80	3.61	3.59	4.09	3.86	4.04	3.92	4.14	4.46	4.39	3.37	3.35
TC (CFU/100 mL)	$3.97.10^5$	$3.71.10^5$	$1.54.10^4$	$1.24.10^4$	$3.61.10^4$	$2.78.10^4$	$8.55.10^4$	$3.51.10^4$	$4.01.10^4$	$3.44.10^4$	$2.09.10^4$	$1.28.10^4$	$7.61.10^3$
pH	7.57	7.37	7.49	7.48	7.48	7.00	7.21	7.10	7.19	7.03	7.44	7.02	7.15
BOD$_5$ (mg L^{-1})	35.56	19.50	11.38	13.31	14.88	10.13	14.19	11.06	12.06	12.69	11.06	8.94	14.31
TP (mgP L^{-1})	1.03	0.68	0.53	0.55	0.67	0.32	0.37	0.28	0.35	0.35	0.33	0.40	0.36
T (°C)	19.7	18.6	18.2	18.4	18.8	18.4	18.6	18.8	18.9	19.0	19.3	19.3	19.3
TN (mgN L^{-1})	47.26	33.55	31.17	30.59	33.31	27.44	31.74	32.05	32.20	29.67	29.68	26.35	24.69
Nitrate (mg L^{-1})	4.55	2.93	4.15	4.10	4.58	3.43	3.98	6.16	5.21	3.73	3.78	4.11	4.29
Nitrite (mg L^{-1})	0.11	0.14	0.19	0.18	0.18	0.18	0.20	0.16	0.16	0.16	0.16	0.17	0.11
Turbidity (NTU)	33	16	11	11	14	15	17	17	15	14	14	13	17
TS (mg L^{-1})	319.16	216.60	178.67	185.29	192.79	164.62	162.17	162.68	160.67	169.12	239.92	139.27	164.83
WQI	25	29	38	39	36	39	36	37	38	38	41	40	40
Flow rate (L s^{-1})	23.99	41.06	208.08	293.65	398.37	612.87	677.46	689.87	733.59	820.63	792.09	810.67	743.00

DO=dissolved oxygen; TC=Thermotolerant coliforms; BOD$_5$=Biochemical oxygen demand; TP=Total phosphorus; T=Temperature; TN=Total nitrogen; TS=Total solids.

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3.2. Pollutant load

Additionally, the pollutant load values were calculated with respect to some parameters such as BOD, phosphorus, TDS, TN, nitrite and nitrate. The concept of pollutant load involves the mass of a pollutant that is discharged into the water for a period of time (Metcalf and Eddy, 2013). The measurements of concentrations previously considered for WQI scores computing and the flow measurements were used to obtain the pollutant load values. The results are presented in Figure 2.

As can be seen in Figure 2A, the water flow increased gradually from nearly 24 L s^{-1} at the source and reached an average value of 743 L s^{-1} at the mouth, where it flowed towards Caveiras River.. Although the flows were measured on days which were not preceded by precipitation, a confidence interval that may reach 51.6% of average flow rate (point 11) was obtained, which demonstrates that the flow in the river is influenced by the discharge of raw sewage or even its disposal in urban drainage systems. The water flow showed insignificant variations from point 10 as this area has the lowest number of constructions in the watershed. These measurements of water flow allowed us to compute the pollutant load transported by the river. We observe from Figures 2B to F that all the pollutant load values increase in the downstream direction, which certainly resulted from various contributions of sewage or wastewater along the river. With regard to the BOD$_5$ (Figure 2B), the average pollutant load ranged between 3 to 39 Kg h^{-1} within the measurements. The municipality of Lages has a sewage treatment plant which partially receives all the sewage flow generated in the city (around 20%). As a consequence, a large amount of the raw sewage is released into the Carahá River. Along with its extension, no recovery tendency was observed in the water quality due to the biological digestion (i.e. the BOD$_5$ continuously increased to the mouth). This could be explained by the time of concentration in the River and the constant addition of organic pollutant load to the water.

Similarly, analysing the pollutant load of phosphorus and total nitrogen (Figures 2C and 2D), the values reached 1 and 80 Kg h^{-1}, respectively. The control of the release of these nutrients into water bodies is of great concern to the basin management. The Caveiras River transports these nutrients to locations where there are dams built. In these places, the lentic ecosystem shows potential for eutrophication (Siziba, 2017). Therefore, knowledge of the phosphorus and nitrogen load permits the calculation of the mass of nutrients that will reach dams and thus assists in developing actions to control these releases. In this way, the measurement of pollutant load which is transported to the Caveiras River is more useful than the data based on concentration for Carahá River.

In addition, loads of nitrate and nitrite presented values equal to 11.48 and 0.30 Kg h^{-1} (Figures 2E and 2F), respectively, indicating that the sewage contamination is recent since these values are smaller than the load of the sum of organic nitrogen and total ammonia nitrogen (Von Sperling, 2005). Jani and Toor (2018) studied the Braden River, Manatee River, and Tampa Bay estuary in the United States of America, which is also mainly impacted by sewage disposal. The authors also concluded that organic nitrogen was the most common nitrogen form, ranging from 46 to 83%. The inorganic nitrogen forms NOx accounted for 7%. In addition, the authors discussed the effect of the dilution in the estuarine area by the tidal marine waters. The concentration of nitrogen decreased from freshwater to the estuarine ecosystem. In our study, we also observed a tendency for the nitrogen concentration decrease in the points close to the mouth, i.e. from point 10 (Table 1). As the Caveiras River is the water body used for freshwater abstraction, it is assumed to have a better water quality. Therefore, the dilution of the Carahá River in the mentioned points should occur. Alternatively, Li et al. (2019) carried out a study in the Xinjiang River, located in Southern China. The authors aimed to identify the sources and transformations of nitrate in the river. Many sources were identified, such as wastewater discharge and use of fertilizers. The concentration of nitrate was lower than

3.0 mg L^{-1}, which was compatible with the values obtained in our study (Table 1). The authors used techniques based on nitrate isotopic signatures and were able to describe the nitrate transformations in the river. The results showed that 12% of the nitrate is removed by denitrification process in the river. Based on this result, the denitrification could be an effect which could explain the variation in the nitrate concentration in the sampling points close to the mouth of Carahá River. This observation corroborates with the load values for nitrate shown in Figure 2F. As the load is a parameter which is not influenced by the dilution effects, the decrease in nitrate load shown in Figure 2F must be due to denitrification.
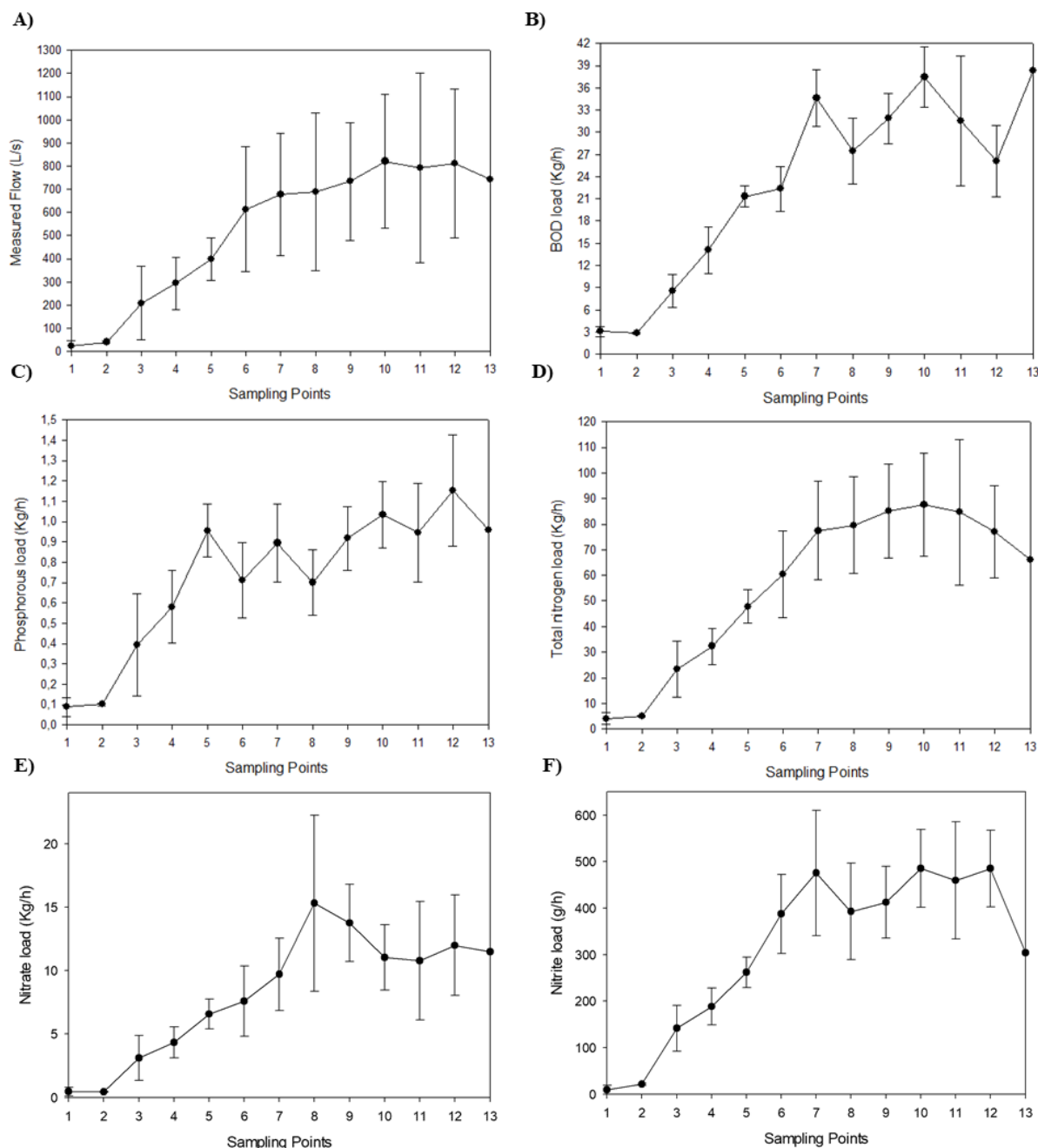
Figure 2. Flow measurements (A) and pollutant load for BOD (B), Phosphorous (C) and Total Kjeldahl Nitrogen (D).

Overall, it can be observed that there is an increase in the calculated load for the first sampling point in relation to the point at the mouth of the Carahá River. The concentration data

presented in the form of WQI showed a constant behaviour of concentration from point 4 (Table 1), which creates the false impression that all points in the river have the same level of contamination. However, observing the data in Figure 2, it is possible to see an increase of up to 33 times, for instance, for the parameter nitrite. That is to say, the load transported 9.1 g h^{-1} of nitrite and the value reached 300 g h^{-1} at the mouth. From Figure 2, we can see more clearly the continuous increase in water contamination along the basin, in contrast to the results expressed by the water quality index. In other words, the use of concentration values and the consequent computing of WQI provided results that did not show the tendency of pollution increasing along the basin, which may generate misinformation about the impact on the water body.

4. CONCLUSIONS

The results obtained in this study showed that the monitoring of Carahá River by pollutant load concept is more representative of the environmental impacts once it is independent of the dilution effects. The river is increasingly impacted from the source to the outlet, which could be detected by the pollutant load values. On the other hand, the water quality index showed similar values and was not effective to express the progressive contamination in the watershed. The use of the calculation of load for Carahá River is, therefore, a tool for assessment of pollution that can provide more appropriate information for the management of this water resource.

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