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Influence of land use and occupation on the water quality of a microbasin in the southwestern Amazon

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Abstract. Water resource management in Brazil is constantly evolving, and greater knowledge about this resource allows better planning and more sustainable uses. In Brazil, the improvement of water resource management faces the difficulty of implementing the instruments of the National Water Resources Policy, such as classification of water bodies. Thus, to help improve the water management instruments in the country's northern region, the objective of the present study was to diagnose the influence of land use and occupation on the water quality of the Igarapé Nazaré microbasin. For this purpose, indirect methods of landscape analysis were applied based on the processing of remote sensing images in a GIS. For the water quality analysis, 10 collection points were selected in the watershed, with samples collected at each one in four periods (high water; HW/LW transition; low water; LW/HW transition). In the collected samples, 14 parameters were analyzed, namely: temperature, pH, electrical conductivity; turbidity; water transparency and depth; dissolved oxygen; chlorophyll a, ammonia, nitrite, nitrate, total phosphorus and dissolved phosphorus; total coliforms and E. coli. The spatial analysis showed that the microbasin has about 84% anthropized territory, with emphasis on agriculture, and sources of pollution from industries, fish farming and domestic sewage. Parameter analyses showed high values of total phosphorus (0.005 - 27.55 mg.L-1), total coliforms (4,103 - 1,09,106 CFU) and E. coli (0 - 5.8,105 CFU), and low DO concentration (0.0 - 8.33 mg.L-1), below the official limit established in all periods analyzed The water quality of the Igarapé Nazaré microbasin was found to suffer strong anthropic interference, requiring improvement of the sanitary infrastructure of city of Ji-Paraná, for maintenance of the watershed in class 2.

1 Introduction

Water resource management in Brazil is constantly evolving, and greater knowledge of water quality can enable better planning and more sustainable use (Rosa & Guarda, 2019). Therefore, knowledge about the activities that affect a basin's water quality is an important tool in the water management process (Lima et al., 2018). Likewise, knowledge about the land use and occupation in watersheds supports territorial and environmental planning (Vargas et al., 2019).

Although Brazil has a well-intentioned National Water Resource Policy (PNRH in the Portuguese acronym), specifying various instruments for management of watersheds, these instruments have proved hard to implement in the majority of cases. An example is the classification of water bodies, where in 2018 only 13 states had legislation or regulations classifying some or all of their water bodies (ANA, 2019). Progress toward this goal has proven to be slow, with many hurdles hampering the process, making it necessary to create more effective programs (Machado et al., 2019). In this respect, the states of the North region stand out, in which no water bodies have been properly classified (Lopes et al., 2020).

Therefore, more information is necessary to hasten progress in water management. This can be promoted by the use of geoprocessing tools (Flauzino et al., 2010), implementation of effective water quality monitoring, and production of information to support policymakers' decisions regarding sustainable water use and ecological restoration of watersheds (Avila, 2016; Vigiak, 2016; Britto, 2018).

Looking toward the establishment of these initiatives in the country's North region, our objective in this study was to diagnose the influence of land use and occupation on the water quality of the Igarapé Nazaré microbasin.

2 Material and Methods

2.1 Study area

The Igarapé Nazaré microbasin (11°11'S; 61°30'W) is located in the Machado River basin, in the municipalities of Ji-Paraná and Presidente Médici, state of Rondônia, Brazil. The predominant climate is wet tropical and hot, with a rainy season from January to March, a wet-dry transition period from April to June, a dry season from July to September, and a dry-wet transition period from October to December. The average temperature ranges from 24 °C to 26 °C (SEDAM, 2012). The microbasin covers an area of approximately 106 km2, and the main economic activities are farming, stock breeding, meat packing and fish farming. Water samples were obtained from 10 points (Figure 1). The characteristics of each point are described in Table 1.

2.2 Digital image processing (DIP)

The first phase of the study involved obtaining satellite images from the Land Remote Sensing Satellite (LANDSAT), made available free of charge, obtained from the online platform of the National Space Research Institute (INPE). We used images from the Operational Land Imager (OLI) sensor of LANDSAT 8. These satellite images were used because they are the most longstanding and important sources of data to analyze the evolution of planetary land cover (Bertucini Junior & Centeno, 2016; Souza, 2017). We used the images from the OLI sensor for 2019.

To delineate the Igarapé Nazaré microbasin, we employed the QGIS 2.18.13 free software, applying a digital elevation model (DEM), with SRTM images obtained from the platform of the Brazilian Agricultural Research Company (Embrapa, the federal government's agricultural research agency). These images were processed with the QGIS geoprocessing tools.

The second phase was the DIP, for which we also used the QGIS 2.18.13 free software, whereby the images acquired were submitted to a correction and recording process using DATUM SIRGAS 2000 to perform the sequence of segmentation and classification of the images. After classification, the data were converted from matrix to vector format for subsequent application of map algebra and then generation of thematic maps. The image classification process was based on the supervised maximum likelihood classification method, which has already produced good results for land use and occupation analysis in the state of Rondônia (Mello et al., 2012). For this purpose, we used three image bands from each sensor for RGB composition, with subsequent selection of samples for supervised classification, into bands 6 (R), 5 (G) and 4 (B).

2.3 Water samples

Water sampling was carried out in 2019, in March (high water–HW), June (high water to low water transition–HW/LW), September (low water–LW) and December (low water to high water transition –LW/HW). When collecting the samples, we also identified places with discharge of domestic and industrial wastewater, and tallied the number of industrial concerns, areas of irregular dumping of solid waste and cattle breeding areas, among other land uses that can potentially pollute the Igarapé Nazaré microbasin.

2.4 Analysis of the water quality variables

The following variables were measured in the field in the surface water at each collection point with an Akso Ak88 multi-parameter meter: temperature (T°C); electrical conductivity (EC) and potential of hydrogen (pH). Samples were also taken to the laboratory under refrigeration for other analyses, as described by the Standard Methods for the Examination of Water and Wastewater (APHA, 2015) and the National Guide for Collection and Preservation of Samples (2011).

The turbidity was measured with a portable turbidimeter (Hach model 2100P). The dissolved oxygen (DO) was measured according to the Winkler method (APHA, 2015) and the transparency was determined in the field using a Secchi disk. The concentrations of ammonia, nitrite, nitrate, total phosphorus and dissolved phosphorus were ascertained by spectrophotometry, according to the analytic methods described in APHA (2015). For this purpose, the water samples were filtered through glass microfiber filters (0.45µm, Whatman AP 20), except for determination of total phosphorus, which was performed with unfiltered water.

The chlorophyll a was analyzed using 95% ethanol, according to the method described by Pereira (2011). The microbiological quality was determined by measuring the density of fecal coliforms (Escherichia coli) and of total coliforms by chromogenic membrane filtration, as described in APHA (2015).

2.5 Statistical treatment

Analysis of variance (ANOVA) was used to evaluate the seasonal differences of the parameters considered in the case of parametric data, as determined by the Shapiro-Wilks test, and the Kruskal-Wallis test was applied in the case of nonparametric data. All the tests were performed with the free statistical program Past 3.25. The data were also submitted to multivariate analysis and principal component analysis (PCA), with the objective of verifying the relationship of the variables between collection periods, to detect possible patterns. For the PCA, the data were arranged in a matrix, and the statistics were computed with the program XLSTAT for Excel. In all analyses, the results were considered significant with $p \leq 0.05$.

3 Results and Discussion

3.1 Land use and occupation

The geoprocessing allowed obtaining information on the land use and occupation in the Igarapé Nazaré microbasin, as well as identifying the main point sources of pollution, as depicted in Figure 2.

The main sources of effluents identified in the microbasin were associated with food processing (two sources), meat packing (five sources) and treated domestic sewage (two sources, one from a housing complex and the other from a penitentiary). All these sources released effluents rich in organic matter (Cardoso, 2015; Marçal & Silva, 2017; Lunelli, 2019), which when not treated adequately pose risks to water quality. Barbosa (2012), in analyzing the water quality of the Pirarara River in the municipality of Cacoal, Rondônia, observe that the impairment of water quality was mainly due to release of domestic and industrial wastes, by identifying contaminants typical of these types of effluents at the most degraded points.

Pasture for grazing livestock (figure 3) is the main land use in the microbasin (73.3 km2), followed by native or secondary vegetation (17.4 km2) and urban area (11.3 km2). According to the Brazilian Institute of Geography and Statistics (IBGE, 2017), animal husbandry is one of the main economic activities in the state of Rondônia, which occupies sixth place in the national ranking of cattle herd size (14 million head). This explains the large number of slaughterhouses (n =5) in the microbasin.

Besides the domestic and industrial point sources of pollution identified, there are also aquaculture sources (classified as water bodies, with area of 3.18 km2) in the microbasin. This is a rapidly expanding economic activity in Rondônia (Pereira et al., 2019). This activity uses large amounts of water and produces effluents rich in organic matter, similar to domestic waste, posing a water quality risk if not adequately managed (Macedo & Sipaúba-Tavares, 2010; Assunção et al., 2016).

Besides the point sources, there are several diffuse sources of pollution. Their origin is usually difficult to pin down and the quantities are hard to calculate due to the many sources and causes, such as soil erosion, runoff containing particulate matter such animal manure, soot and ash from land clearance by burning, among other factors, as discussed by Sodré (2012), Of particular note is that according to the Sewage Atlas of the National Water Agency (ANA, 2017), only 18.6% of the domestic sewage in Ji-Paraná is submitted to some type of treatment, and the flow of raw sewage into Igarapé Nazaré was 29.1 L/s that year.

Studies of other microbasins in the state, such as Ji-Paraná (Nunes et al., 2018) and Ouro Preto do Oeste (Prestes et al., 2018), as well as of the city of Manaus in the state of Amazonas, have shown proportions of anthropized areas similar to those found by us, with values of 62.4% (Manaus), 85.94% (Ouro Preto do Oeste) and 95.5% (Ji-Paraná).

3.2 Relationship of water quality and land use and occupation

Article 15, § 2, of Resolution 91/2008 from the National Water Resources Council specifies that if sufficient information is not available to classify a surface freshwater body, class 2 can be adopted. Therefore, the parameters defined by Resolution 357/2005 from the National Environmental Council (CONAMA) for class 2 are used as reference values for comparison of the results found in this study.

The average water temperature for the four periods analyzed (Figure 4a) was 30 °C. That value is similar to those found in studies of microbasins near the Igarapé Nazaré microbasin. Trindade et al. (2019) studied five water bodies in Ji-Paraná and found values ranging from 25 °C to 30 °C in the HW/LW transition period. In turn, in the Igarapé Mangueira microbasin, also located in the municipality of Ji-Paraná, the temperatures varied between 26 °C and 32 °C in the HW and LW periods according to Sousa et al. (2019).

Figure 4a also shows that the maximum temperature in the HW period was recorded at P5 (37.9 °C). That result is certainly related to factors like the absence of a permanent protection area and the influence of the land use and occupation in the surrounding area, since this point receives large amounts of effluents from two meat packing plants and part of the urban area of Ji-Paraná, as we observed in the field.

The ANOVA results did not identify significant changes in temperature over the four seasonal periods ($F = 2.63$; $p = 0.065$). According to Nobre et al. (2009), the mean air temperature in the Meridional Amazon region, where Rondônia is located, varies little, ranging between 24 °C and 26 °C, with annual amplitude that can reach 3 °C to 4°C.

Table 2 contains the values of water depth and transparency. For P4, the transparency values are very low compared to the water depth, demonstrating the receipt of organic and inorganic particulate matter of natural or anthropic origin. P4 is the point where a small tributary flows into Igarapé Nazaré, and is near a point of discharge of effluents from a meat packing plant. The effluents from slaughterhouses contain a high concentration of organic matter, which can degrade the water quality if not treated properly (Cardoso, 2015).

The ANOVA results did not show significant variations in the averages of the periods for water depth and transparency ($F = 1.17$ and 1.68; $p = 0.34$ and 0.19). Siqueira et al. (2012), studying the water quality of the Parauapebas River (Pará State), reported that periods with less rainfall tended to have greater water transparency due to the lesser leaching of organic matter. However, for P4 we observed the opposite, which can be explained by the entrance of wastewater from the nearby meat packing plant, so the smaller flow in the low water period suffers a greater impact of the organic load in the effluent received.

Phosphorus is an element that occurs naturally in water, but in high amounts it is considered a pollutant, mainly in still surface water, where it provokes eutrophication, increasing the population of algae and plants, which can consume the dissolved oxygen in the water and kill fish (Lamparelli, 2004; Klein & Agne, 2012).

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The results for phosphorus (Figures 4, b and c) in all periods and at practically all the sampling points were above the threshold of 0.1 mg.L-1 for class 2 lotic water bodies set by CONAMA Resolution 357/2005. Silva et al. (2019), in analyzing the total phosphorus concentration in urban springs in Ji-Paraná, observed that of the 8 points analyzed, the concentration in the water of all of them was above that value in all periods analyzed. Their results together with ours demonstrate that anthropic activities degrade the water quality of streams in urban areas even at their origin.

Points P1, P2 and P3, located in a relatively well preserved rural APP, were the only ones to present concentrations below 0.1 mg.L-1 in all the periods. The others (P4 to P10) all had levels greater than 0.1 mg.L-1, with highlight on P4, which in the low water period had total phosphorus concentration of 27.55 mg.L-1. The highest concentrations of total phosphorus were found in the low water period at all the points sampled.

The lowest concentrations of dissolved phosphorus were also found at points P1, P2 and P3, while the highest concentrations were found at P4 (2.06 mg.L-1) and P7 (0.12 mg.L-1). These values can reflect the presence of aquatic flora, since this is the main form of phosphate assimilated by aquatic plants (Esteves, 2011).

Factors such as the presence of slaughterhouses and food processing plants (which occupy 10.66% of the Igarapé Nazaré microbasin, located around the urban perimeter), along with low flows and volumes of water in the stream and entry of varied effluents are likely reasons for the high levels of phosphorus.

Therefore, it is extremely important to adequately treat the effluents generated by these industrial concerns, since the organic load is high (biological oxygen demand of up to 4,200 mg.L-1 according to Aguilar, 2002). Excess phosphorus can cause serious harm to aquatic ecosystems (Thebaldi et al., 2011; Orssatto et al., 2018; Lunelli et al., 2019).

With respect to nitrogen compounds, in the case of nitrate (Figure 4f), the majority of the points had concentrations higher than the limit specified by CONAMA Resolution 357/2005, of 10 mg.L-1 in the HW and HW/LW periods. The concentrations of ammonia (Figure 4d) were also above the regulatory threshold of 3.7 mg.L-1/pH < 7.5 in the low water period (varying from 0.005 to 4.77 mg.L-1). In turn, nitrite was below the value of 1.0 mg.L-1 set by the Resolution during all the sampling periods. The presence of high concentrations of these nitrogen compounds can seriously harm aquatic flora and fauna, due to eutrophication, increased water toxicity and proliferation of algae, among other negative effects, as well as posing risks to human health (Zoppas et al., 2016; Reismann et al., 2017).

Of particular relevance during the low water period, when the ammonia concentrations were above the limit of 3.7 mg.L-1 (CONAMA Resolution 357/2005), there were episodes of fish mortality in Igarapé Nazaré and one of its tributaries, Córrego Bonzinho, suggesting that one of the causes of the fish die-off was the high concenration of ammonia in the water column.

One of the factors causing the high concentration of nutrients in the microbasin is likely the presence of many fish farming operations in the region (29 observed).

For nitrite (Figure 4e), there was no significant variation in the concentrations between the periods ($p>0.05$), reflected in the small amplitude of the pairwise differences between them, where the smallest difference (<0.005 mg.L-1; points 1, 2, 3, 4 and 10 in all periods) and greatest difference (0.036 mg.L-1; point 9, low water) found in all the samples were well below the figure specified in CONAMA Resolution 357/2005. Nitrite is the intermediate form between nitrogen compounds (Esteves, 2011; Rodrigues, 2017), and the low values found in all periods (smaller than 0.04 mg.L-1), can be explained by the fact that nitrite is rapidly consumed by processes of nitrification, denitrification and anammox, reducing the concentration in the water. In contrast, the ammonia and nitrate concentrations were distinct among the four periods (Figures 5c and 5e). For ammonia, there was a significant increase in the LW period. According to Esteves (2011), high ammonia concentrations indicate recent contamination by effluents because of the rapid decomposition of ammonia to nitrite and then to nitrate in aquatic environments. For nitrate, the highest concentrations were found in the HW and HW/LW, indicating a longer time interval for contamination.

According to the ANOVA results of the nutrients, the dissolved and total phosphorus and nitrite did not vary among the seasonal periods (F = 1.31; 0.67; 0.63; p = 0.29; 0.58; 0.6, respectively). In turn, ammonia and nitrate presented significant variations in their average concentration in at least one period (F = 6.16; 60.18; p = 1.8x10-3; 6.8x10-14).

With respect to the dissolved oxygen levels (Figure 5a), only at P2 was the concentration higher than the limit set by CONAMA Resolution 357/2005 (5 mg.L-1) in all the periods. Only the points in the microbasin located in rural areas (P1, P2 and P3) had values below the regulatory threshold, in periods HW (P1 and P2), HW/LW (P2), LW (P2 and P3) and LW/HW (P1, P2 and P3).

The sampling points located in the urban area of Ji-Paraná (P4 to P8), in the periods HW, HW/LW and LW, had values below the regulatory limit, with the exception of P7 in the period HW/LW (5.33 mg.L-1). In the LW/HW period, there were higher DO concentrations, which can be explained by the strong rainfall on the collection day, contributing to the aeration of the water.

As can be observed in Figure 5a, in periods HW/LW, LW and LW/HW, the water at P4 was anoxic, indicating low water quality of the tributary of Igarapé Nazaré. This result can be correlated with the turbidity and electrical conductivity results found for the same point (Figures 5 b and c), which had high values in the same periods. According to Esteves (2011), situations like this can indicate a high load of organic matter in a water body, increasing the consumption of oxygen and making the water improper for drinking and certain other uses.

The low DO values are directly associated with the uses of the basin. Zuffo et al. (2013), who analyzed the main water bodies in Rondônia, associated the low DO observed with stock breeding in the region (the main use of the Igarapé Nazaré microbasin, occupying 70% its area), which was responsible for the high presence of organic matter.

Besides this, the release of organic matter in household wastewater in the urban area directly affected the DO, which was consumed by decomposition of that matter. That fact was also observed by Sousa et al. (2019) in a study of Igarapé Mangueira in Ji-Paraná, where the concentrations of DO varied from 1.21 mg.L-1 to 14.52 mg.L-1.

With respect to turbidity (Figure 5b), the only points that presented values above the threshold established by CONAMA Resolution 357/2005 (100 UNT) were P4 (HW/LW; LW; LW/HW) and P9 (HW/LW).

The high levels of turbidity at P4 (1,000 UNT - HW/LW; 1,000 UNT - LW; 280 UNT - LW/HW) can be related to the low concentrations of DO. Silva (2018), studying the microbasin of Igarapé 2 de Abril in Ji-Paraná, observed that when the turbidity was high, the concentrations of DO were lower due to the presence of organic particles from the discharge of untreated effluents.

Electrical conductivity helps to identify water quality by the greater ability of water to transmit electricity in the presence of dissolved substances. Values above 1,000 µS.cm-1 indicate pollution by household or industrial waste (Brasil, 2014). Values higher than 1,000 µS.cm-1 were found at P4 (1,400 µS.cm-1 – HW; 2,852 µS.cm-1 – HW/LW; 3,390 µS.cm-1 – LW; 2,006 µS.cm-1 – LW/HW), indicating a high level of pollution. This can be explained by the release of industrial wastewater in the stream.

The average results of ANOVA for the parameters DO, turbidity and electrical conductivity did not vary significantly during the four periods (F = 1.789; 0.4893; 0.5357; p-value = 0.1672; 0.6919; 0.6609).

Regarding chlorophyll a, it did not have values above the limit specified by CONAMA Resolution 357/2005 for class 2 water bodies (30.0 µg.L-1), except at P4 for the low water period, with a concentration of 32.319 µg.L-1. In another study in the same region, Santos (2018) investigated the microbasins of Igarapé 2 de Abril and Igarapé Pintado, finding a mean concentration in the latter case of 60.0 µg.L-1.

High chlorophyll a concentration in water bodies can indicate risks of eutrophication and also the presence of cyanobacteria, which can generate contamination by cyanotoxins, degrading the water quality (Marino, 2017; Sousa et al. 2018).

Because the water from Igarapé Nazaré is used to supply industrial establishments, problems of algal blooms can compromise the water quality for these uses. Mariano and Nascimento (2018), studying water treatment for use by a beverage maker, found that the treatment costs increased due to the poor water quality, generating economic losses.

The presence of bacteria of the coliform group was also investigated (Figures 5 d and e). Of this group, Escherichia coli are present in the feces of warm-blooded animals, so their presence in water bodies is an indicator of pollution by untreated sewage (Brasil, 2013).

The densities of total and fecal coliforms found indicated the strong presence of this group in the samples collected in the Igarapé Nazaré microbasin, as can be seen in Figures 5d and 5e.

In periods HW and LW, the presence of E. coli was not found at points P2 and P3, and P1 and P3, respectively. The water at all the other points had values above the limits stipulated in CONAMA Resolution 357/2005, of 1,000 coliforms per 100 mL of water. With respect to total coliforms, no point presented values greater than that threshold.

The high presence of E. coli, as discussed by Silveira et al. (2018), indicates the presence of fecal contamination. According to Machado et al. (2019), this parameter should be considered in defining the classification of water bodies for various uses.The ANOVA results did not show differences in the average values between the periods for the biological parameters chlorophyll a, E. coli and total coliforms (F = 0.52; 0.41; 0.53; p = 0.67; 0.74; 0.67).

Table 3 presents the average values of the variables dissolved oxygen (DO), turbidity, total phosphorus (TP) and total coliforms (TC) found in this study and others carried out in microbasins in Ji-Paraná, as well as the values established by CONAMA Resolution 357/2005 for class 2 water bodies. It can be seen that the values observed for the water samples from Igarapé Nazaré were near those found in other microbasins. This can be attributed to similar factors, such as percentage of urban/rural area in the basin, number of industrial establishments, organic load discharged by domestic wastewater, presence or absence of permanent preservation areas (APPs) and volume of water during the hydrological cycle.

With the objective of identifying possible temporal variations of the variables analyzed, we applied principal component analysis (PCA). Figure 6 shows the projection of the samples and the variables on the axes.

Axis 1 explained 38.86% of the variance of the data and axis 2 explained 13.01%, for a total of 51.87%. The constitution of the axes presented a distribution of points without connection to the sampling periods, indicating a strong anthropogenic influence in the microbasin. Points P1, P2 and P3 were related to high concentrations of DO as a result of proximity to industrial establishments and the urban area of the municipality. In all the periods analyzed, those points were concentrated in the axis of greater water transparency. The other seven points were distributed on the axes with higher concentrations of nutrients, turbidity, electrical conductivity and E. coli. In particular, P4, for all the periods, was fixed on the axis with highest values of total phosphorus and coliforms, reflecting the high level of pollution.

The variables that contributed most to axis 1 were total phosphorus (0.895), dissolved phosphorus (0.878), total coliforms (0.877), E. coli (0.807), Secchi (-0.789), electrical conductivity (0.732), turbidity (0.707), ammonia (0.618), DO (-0.613) and water depth (-0.539). The greatest contributors to axis 2 were nitrite (0.586), nitrate (-0.506) and pH (-0.565). These results are similar to those reported by Toledo and Nicolella (2002) and Oliveira et al. (2017), where microbasins with rural and urban influence presented the highest correlation coefficients.

These results demonstrate that the points with greatest degradation are directly associated with the land use in the urban area of the microbasin and industrial activities. These results are similar to those reported by Finkler et al. (2015), who found that the most significant parameters in the water quality variation in watersheds in the municipality of Caxias do Sul were related to anthropic activities and lack of treatment of domestic and industrial effluents, directly causing degradation of the water quality.

4 Final Considerations

The water quality in the Igarapé Nazaré microbasin was strongly influenced by anthropic activities, mainly in the urban area of the municipality of Ji-Paraná, with values above the thresholds specified in CONAMA Resolution 357/2005 for class 2 water bodies for nutrients and coliforms. The sampling points located in the rural area, especially those near a well-preserved APP, presented the best water quality.

Of the parameters analyzed, only the concentration of nitrite was within the class 2 limit at all the points analyzed in all four periods. Turbidity also was consistently below the threshold with the exception of P4. The levels of pH and chlorophyll a also were only outside of class 2 at one point in all the periods (2.5% of the samples). Ammonia was above the limit only in period LW at 40% of the points sampled. Nitrate was above the limit at 100% of the points in the period HW/LW and 66% of them during HW. For total phosphorus and DO, 70% of the samples were above the threshold. And for total coliforms, 100% of the samples were above the limit for class 2.

For the Igarapé Nazaré microbasin to remain in class 2, it will be necessary to prepare an action plan to improve the sanitary infrastructure of the municipality of Ji-Paraná, along with better monitoring of the industrial effluents discharged into the water bodies, associated with better oversight of rural effluents, mainly from fish farming.

6 Author Contribution

Alan Gomes Mendonça; the article was developed from the master's thesis of the first author. Josilena de Jesus Laureano; student of the same master's degree, she also carried out her dissertation in the same study area, thus collaborating with information and data used in this article. Igor David da Costa: professor of the master's degree, guided the author for the development of the work in all phases of research and data analysis. Ana Lúcia Denardin da Rosa: professor of the master's degree, guided the author for the development of the work in all the research phases, and participation in the field work. Beatriz Machado Gomes: professor of the master's degree, contributed to the collection and processing of laboratory data. Elisabete Lourdes do Nascimento: professor of the master's degree, guided the author for the development of the work in all phases of the research, and participation in the field work and data analysis. Daíse da Silva Lopes: student at the Federal University of Rondonia, member of the Research Group on Surface and Groundwater, was part of the field team and in obtaining laboratory data. Lindolaine Machado de Sousa: student at the Federal University of Rondonia, member of the Research Group on Surface and Groundwater, was part of the field team and in obtaining laboratory data. Tiago de Oliveira Lima: Chemistry technician at the Federal University of Rondonia, member of the Surface and Groundwater Research Group, was part of the field team and in obtaining laboratory data.

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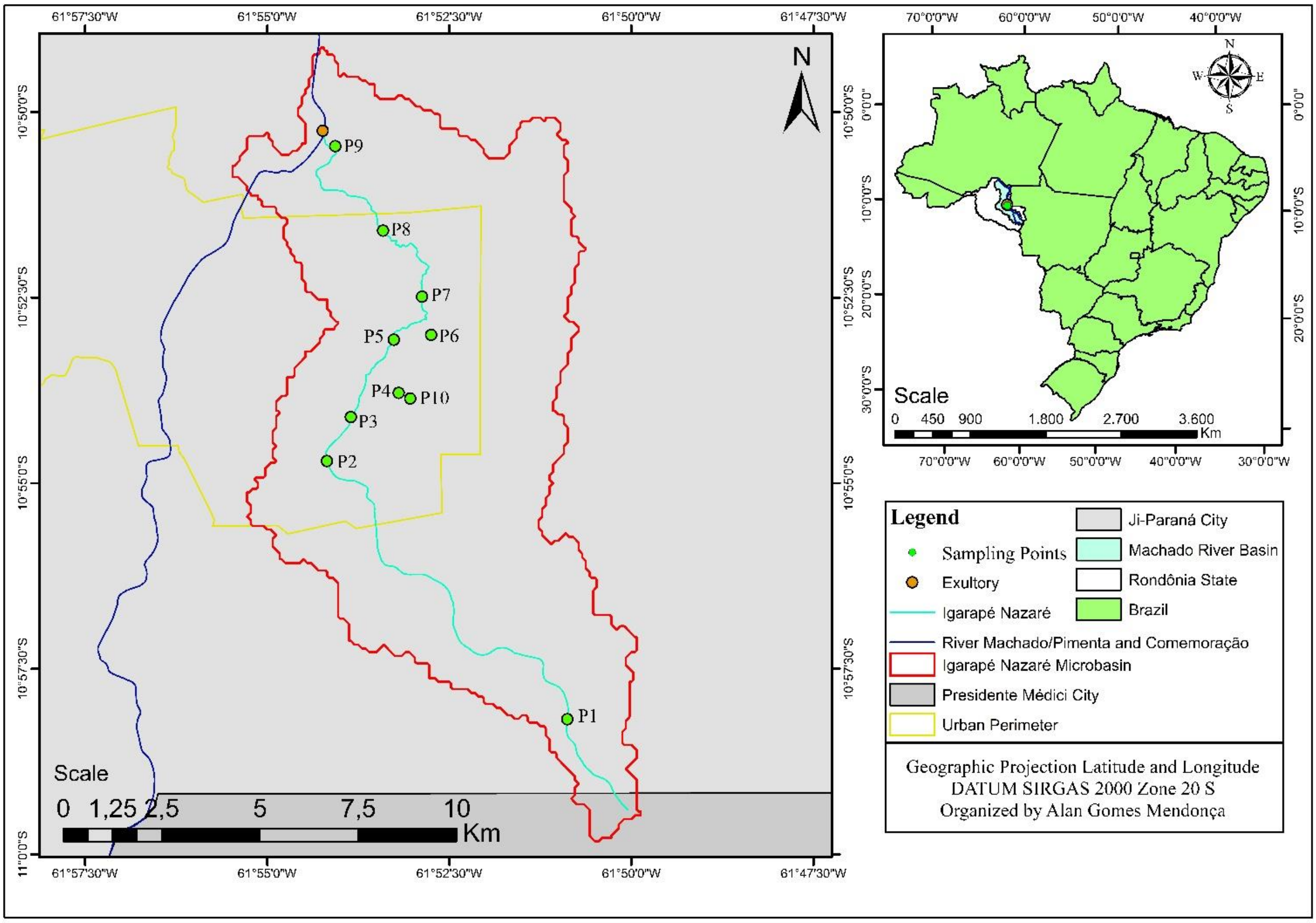

Figure 1: Location of the Igarapé Nazaré microbasin in the state of Rondônia.

Table 1: Characteristics of the sampling points.

Points	Characteristics
P1	Area of buriti palm stands; low anthropization.
P2	Pasture area without permanent preservation area (APP).
P3	Transition between rural and urban area, with partially preserved APP.
P4	Tributary on the right bank of Igarapé Nazaré, APP under restoration, near a slaughterhouse, located in an urban residential zone.
P5	Urban area with preserved APP.
P6	Tributary on the right bank of Igarapé Nazaré, absence of APP, near slaughterhouses.
P7	Transition between rural and urban, partially preserved APP, near a slaughterhouse.

P8	Transition between rural and urban, partially preserved APP and presence of a source of raw sewage.
P9	Flooded area, preserved APP, near the mouth of Igarapé Nazaré.
P10	Tributary on the right bank of Igarapé Nazaré, absence of APP, near a slaughterhouse.

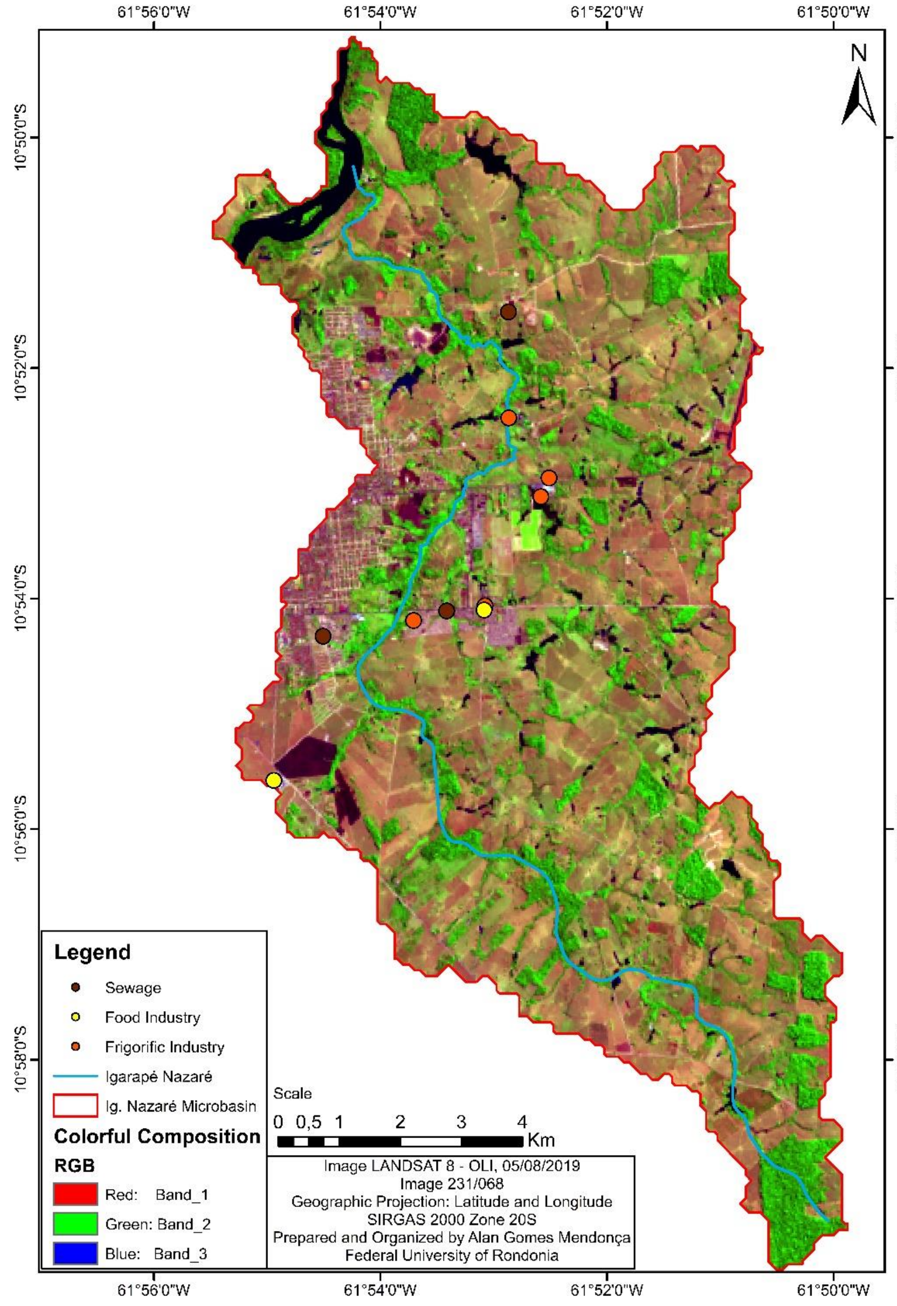

Figure 2: Map showing the location of the point sources of pollution in the Igarapé Nazaré microbasin.

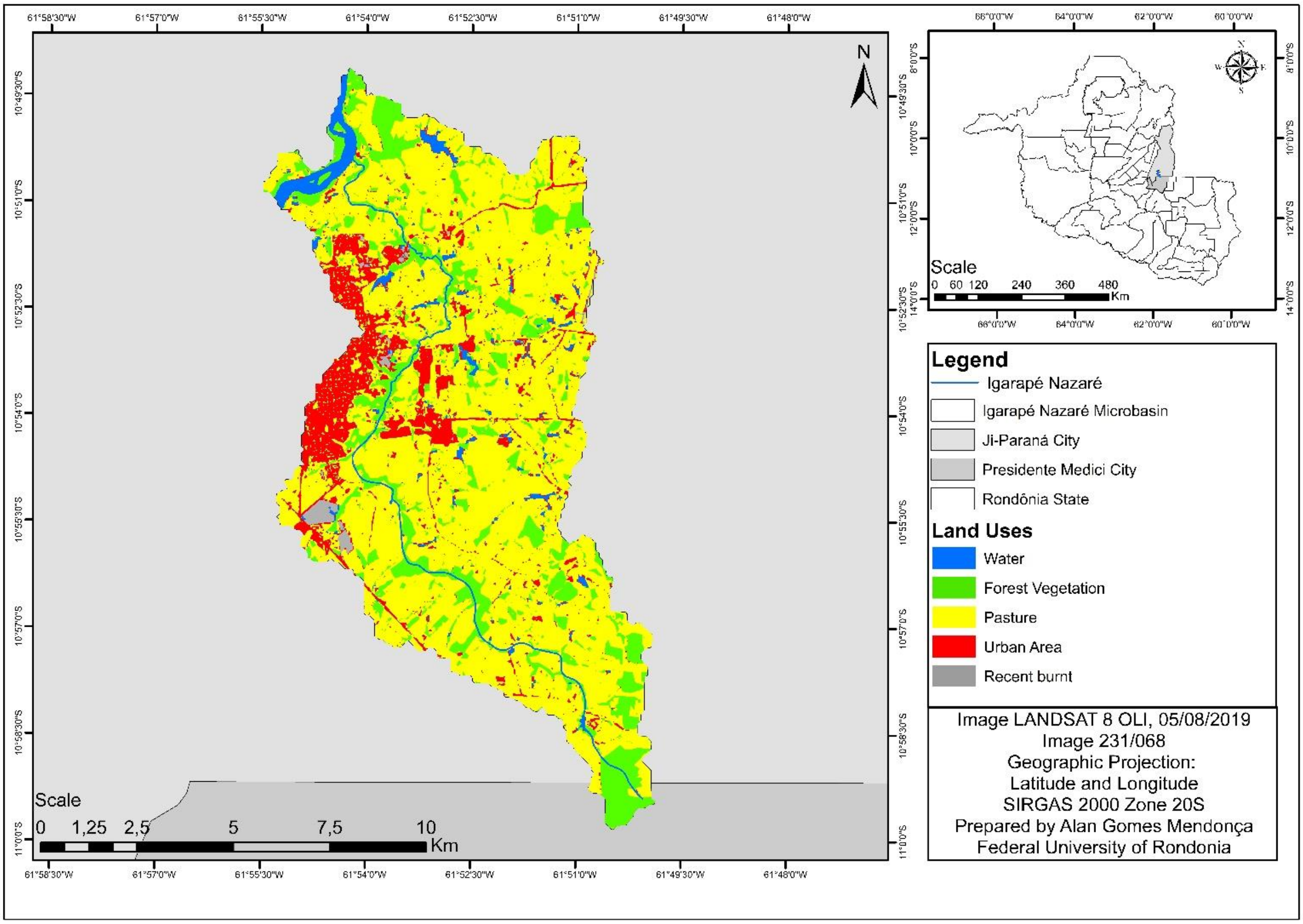

Figure 3: Map of land use classification of the Igarapé Nazaré microbasin (2019).

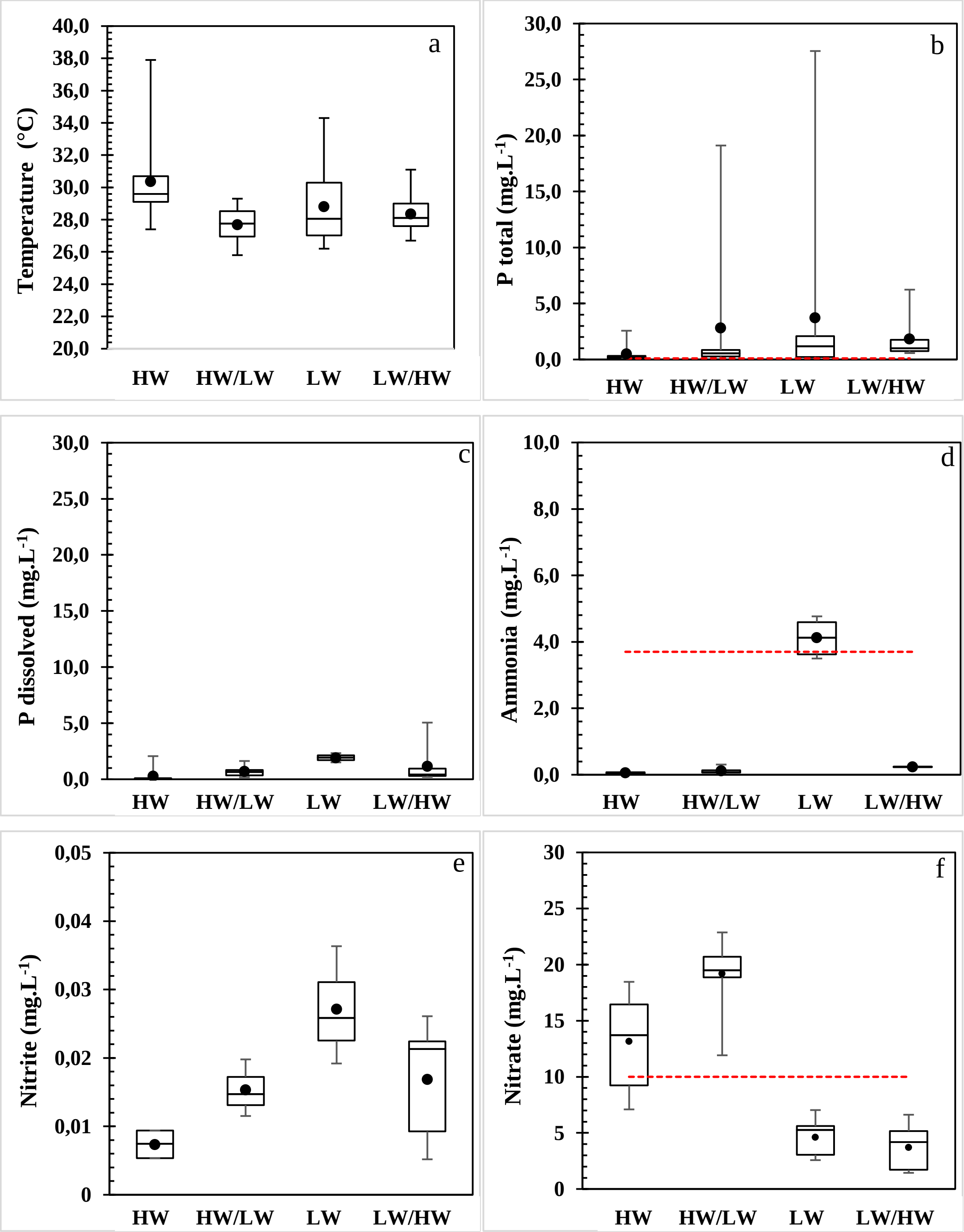

Figure 4: Boxplots for the four periods sampled for a) temperature; b) total phosphorus; c) dissolved phosphorus; d) ammonia; e) nitrite; and f) nitrate. --- reference values of CONAMA Resolution 357/2005 for each parameter. HW: high water; LW: low water.

500 **Table 2: Water depth (cm) and transparency (cm, Secchi disk) in the Igarapé Nazaré microbasin for the four periods sampled.**

	Periods							
	HW		HW/LW		LW		LW/HW	
	Depth	Secchi	Depth	Secchi	Depth	Secchi	Depth	Secchi
P1	38.0	38.0	34.0	34.0	34.0	34.0	28.0	28.0
P2	116.0	92.0	53.0	53.0	43.0	43.0	88.0	84.0
P3	56.5	56.5	34.0	34.0	117.0	64.0	30.0	30.0
P4	51.0	16.0	33.0	0.0	33.0	0.0	32.0	8.0
P5	60.0	54.0	44.0	44.0	26.0	10.0	38.0	38.0
P6	47.0	47.0	26.0	26.0	15.0	15.0	39.0	39.0
P7	28.0	28.0	28.0	28.0	21.0	21.0	26.0	26.0
P8	75.0	52.0	44.0	44.0	17.0	17.0	34.0	34.0
P9	10.0	10.0	24.0	24.0	22.0	22.0	98.0	40.0
P10	-	-	22.0	22.0	26.0	12.0	24.0	19.0

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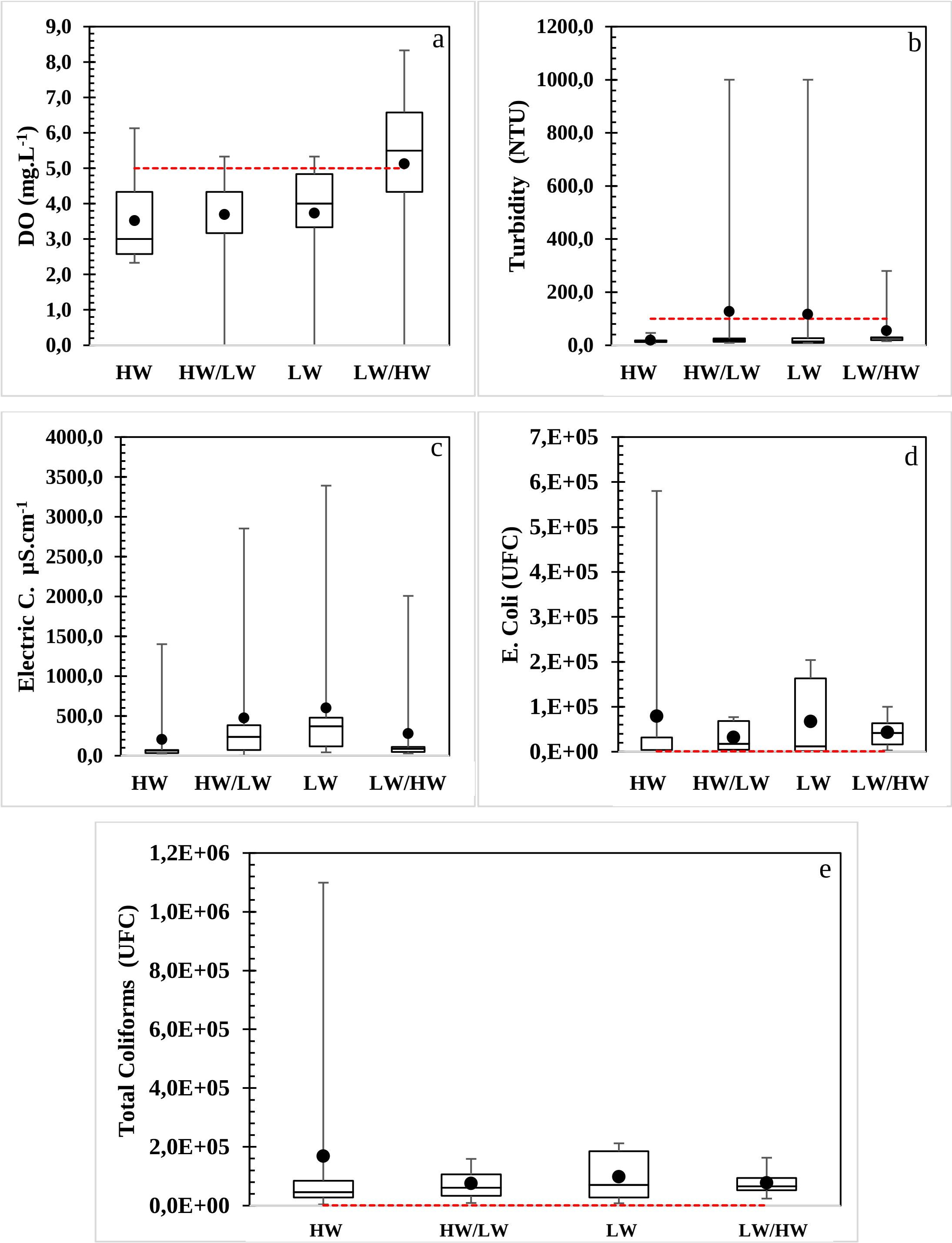

Figure 5: Boxplots for the 4 periods analyzed for: a) dissolved oxygen, b) turbidity, c) electrical conductivity, d) E. Coli, and f) total coliforms. --- Reference value of CONAMA Resolution 357/2005 for the parameters analyzed. HW: high water; LW: low water.

515 **Table 3: Comparison between the average vales of some parameters analyzed in the Igarapé Nazaré microbasin (present study) and other microbasins in the municipality of Ji-Paraná.**

	DO	Turbidity	TP	TC	
Ig. Nazaré	3.85 mg.L^{-1}	59.55 NTU	1.46 mg.L^{-1}	125,600 UFC	Present study
Ig. Dois de Abril	2.2 mg.L^{-1}	60.44 NTU	1.34 mg.L^{-1}	151,442 UFC	Silva et al. (2019)
Ig. Riachuelo	5.71 mg.L^{-1}	-	0.2 mg.L^{-1}	296,844 UFC	Bezerra, (2014)
Ig. Pintado	1.2 mg.L^{-1}	225.25 NTU	12.28 mg.L^{-1}	8,000,000 UFC	Rocha et al. (2014)
Ig. Mangueira	4.57 mg.L^{-1}	39.52 NTU	0.17 mg.L^{-1}	62,379 UFC	Sousa et al. (2019)
Class 2	>5.00	<100	0.1 mg.L^{-1}	1,000	CONAMA Resolution 357/2005

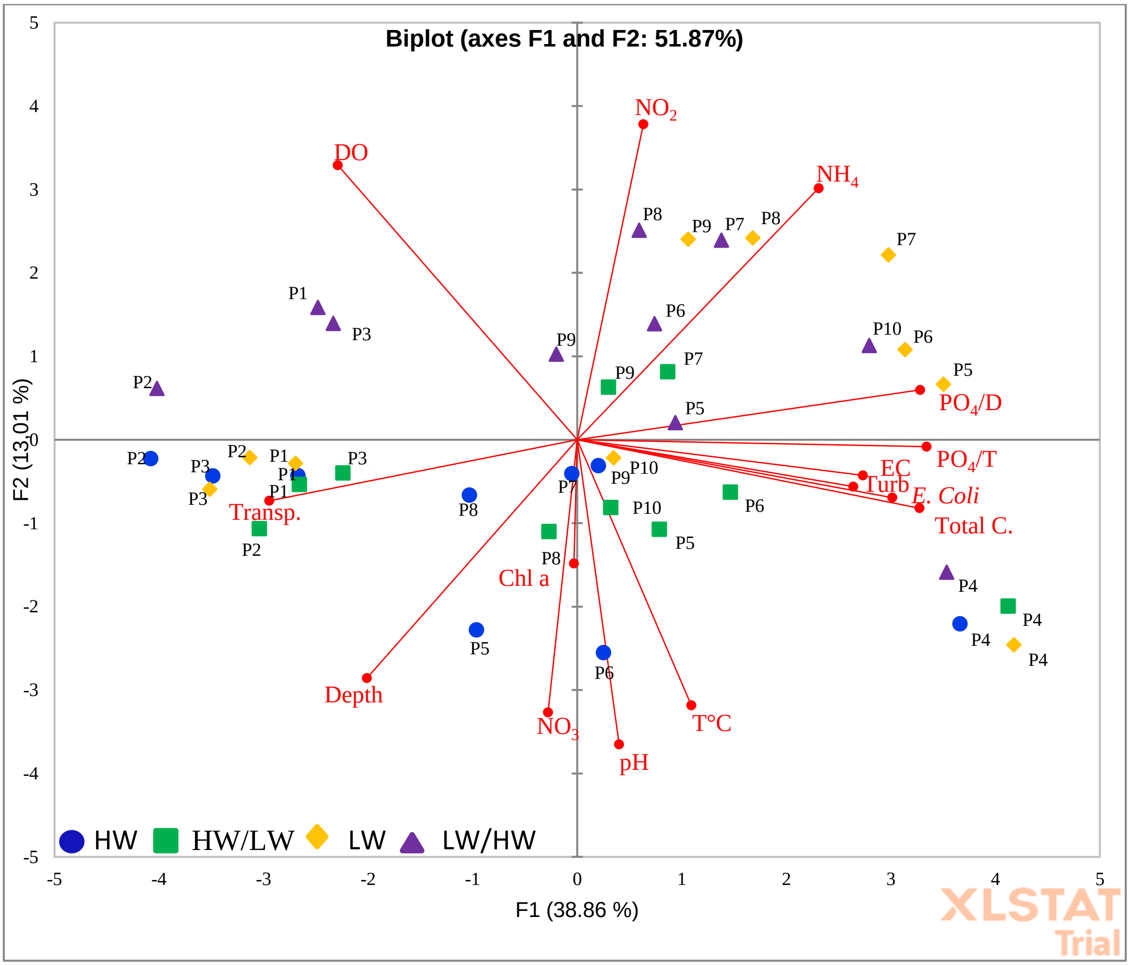

Figure 6: Data projection of principal component analysis (PCA) of the variables recorded in the Igarapé Nazaré microbasin. PO4: dissolved and total phosphorus; NH4:ammonia; NO2: nitrite; NO3: nitrate; DO: dissolved oxygen; *E. coli*; Total coliforms; Chl a: chlorophyll a; Transp.: Transparency; Turb.: turbidity; T°C: temperature in degrees Celsius; pH: hydrogeonic potential; EC: Electric conductivity. HW: high water; LW: low water.