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EVALUATION OF WATER QUALITY AND BATHING SUITABILITY IN AN URBAN STRETCH OF THE ACRE RIVER, ACRE, BRAZIL

AVALIAÇÃO DA QUALIDADE DA ÁGUA E BALNEABILIDADE EM UM TRECHO URBANO DO RIO ACRE, ACRE, BRASIL

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ABSTRACT

The effects of human activities in an urban stretch of the Acre River, Rio Branco, Acre, were evaluated by means of the bathing conditions and Water Quality Index (WQI). Five sites were selected along the stretch studied and sampling was carried out at different stages of the hydrological cycle (dry, flood, full and ebb). To calculate the WQI nine variables were used: turbidity, water temperature, total solids, thermotolerant coliforms (fecal), dissolved oxygen, total phosphorus, total nitrogen, pH and BOD. For the water classification as bathing suitability, the CONAMA 274/2000 Resolution was applied. The results indicated that the seasonality did not change the water qualify of the Acre River, being 40% of the samples in the good quality and 60% in the regular quality. As for bathing, 50% of the samples were classified unsuitable for primary contact recreation. The lowest densities of fecal coliforms were found in the high water period revealing, possibly, the influence of the flood pulse on the dilution of the coliform loads during the flood period and the low capacity of the Acre River to dilute the load of coliforms in the dry period.
Key Words: water quality index; thermotolerant coliforms; flood pulse.

RESUMO

Os efeitos das ações antrópicas em um trecho urbano do rio Acre, Rio Branco, Acre, foram avaliados por meio das condições de balneabilidade e do Índice de Qualidade da Água (IQA). Foram estabelecidos cinco pontos de coleta, ao longo do trecho estudado, sendo que as amostras foram coletadas abrangendo etapas do ciclo hidrológico (seca, enchente, cheia e vazante). Para o cálculo do IQA foram utilizadas nove variáveis: turbidez, temperatura da água, sólidos totais, coliformes termotolerantes (fecais), oxigênio dissolvido, fósforo total, nitrogênio total, pH e demanda bioquímica de oxigênio. Em relação ao critério de balneabilidade, foi utilizada a Resolução CONAMA 274/2000. Os resultados indicaram que a sazonalidade não alterou a qualidade da água do rio Acre, dos quais 40% dos locais amostrados considerados como qualidade *boa* e 60% *regular*. Quanto à balneabilidade, 50% dos locais amostrados foram classificados *impróprios* para recreação de contato primário. As menores densidades de coliformes fecais foram encontradas no período de águas altas revelando, possivelmente, a influência do pulso de inundação na diluição das cargas de coliformes no período de cheia e a baixa capacidade para diluir a carga de coliformes durante o período seco.
Palavras-Chave: índice de qualidade da água; coliformes termotolerantes; pulso de inundação.

INTRODUCTION

The rivers are subject to numerous disturbances and the aquatic biota response to stimulus, whether natural or anthropogenic (1). The detection results of impacts on rivers depends on the use of biomarkers, combined with physical and chemical variables that affect the ecosystem functioning (2).

Microbiological indicators are important in determining levels of contamination of water and are usually used as indicators of fecal pollution identified by the count of coliform bacteria (3). Fecal coliforms are indicators of water quality of rivers and other aquatic ecosystems that receive sewage. This variable is used by government agencies to classify water bodies in use and sanitary levels, for example, bathing, which is a measure of sanitary conditions of water for primary contact recreation, and potable water for human consumption not offering health risks.

Bacteria that normally inhabit the rivers are responsible for self-purification, however, when the river receives discharges of domestic fresh sewage, due to urban development and proximity, these wastes promote imbalance between the launch and load capacity of the system causing varying degrees of environmental pollution (4). A major disadvantage of bacteriological evaluation is the short survival of coliform bacteria in the presence of sunlight and chlorine. These factors can reduce the number of bacteria present in the sample and lead to incorrect results about the bathing water study (5).

Many Brazilian urban rivers are polluted and silted because of irregular occupation of areas previously forested, urban expansion, the large volume of sediment, industrial effluents, domestic and agriculture that are transported to the streams, changing the quality and quantity of water, and reflecting a decrease in its availability, both for human use and for ecological processes (6,7).

The present study aims to evaluate, on a temporal scale, an urban Acre River stretch, using the Water Quality Index (WQI) as a tool to diagnose water quality assuming that the environmental conditions (ex: flood pulse) is a force factor to improve river water quality.

MATERIAL AND METHODS

The study was conducted over a 9 km of the Acre River stretch, located in the Rio Branco urban area, Acre, Brazil (Figure 1). The Acre River is born in Peru, approximately 300 m above sea level, has a length of 1,190 km, flows at an altitude of 100 m on the right bank of the Purus River in the city of Boca do Acre, AM and nine cities are located on its hydrographic basin. In general, the hydrological regime can be characterized by high water (December-May) and low water (June-November) with clear periods of dry, flood, full and ebb. The basin's climate is hot and humid with average annual temperature around 24.5 °C (8).

Water sampling for physical, chemical and biological analyses was conducted in five sampling sites during the months: September and December/2004, March and June/2005 corresponding, respectively, to hydrological periods of dry to flood, full to ebb (9). The sampling sites were determined considering the urban Acre River stretch used by the Rio Branco city population for multiple use, where the water quality would change risks to human health (Figure 1).

The samples was carried out and transported according to Collection and Preservation of Water Samples Guide (11), and processed in the Food Technology Laboratory and Limnology Laboratory, Federal University of Acre. The following variables were determined: turbity (Turb.) using HACH turbidimeter, model 2100P, total nitrogen (TN) and total phosphorus (TP) by the method of Valderrama (12), total solids (TS) by gravimetric method (13), biochemical oxygen demand (BOD) by the Winkler method with five days of incubation period at 20 °C (14). Measures of pH, water temperature (Temp.) and dissolved oxygen (DO) were performed in the field with YSI probe exploratory brand, model 600R.

For thermotolerant coliforms (fecal coliforms – FC) analysis, was used the multi-tube methodology, recommended by the National Environment Council - CONAMA, Resolution No. 274/2000 (15), which is based on Standard Methods (16). The fecal coliforms density is a basic parameter for the waters bathing classification as to their health and appearance. According to the coliforms resolution limits in NMP.100 mL^{-1}, bathing classification considered as: excellent (250), very good (500), satisfactory (1000) and inappropriate (2500) (15).

Water Quality Index (WQI) was calculated using the National Sanitation Foundation Method (USA), modified by (16), in which it outlined these nine variables considered most representative for the characterization of water quality: pH, dissolved oxygen, turbidity, water temperature, total nitrogen, total phosphorus, biochemical oxygen demand, total solids and fecal coliforms. For each variables was assigned a weight according to their relative importance in calculating the WQI, and plotted the average of water quality variation curves according to the same concentrations.

WQI reference values ranges from 0 to 100 tracks of acceptance ranging from Excellent (70 <WQI ≤ 100), Good (51 <WQI ≤ 79), Regular (36 ≤ WQI 51), Bad (19 ≤ 36 WQI) and terrible (00 <WQI ≤ 19) (17). To calculate WQI was used a software developed at the Institute of Environmental Sanitation of PUC – PR (18).

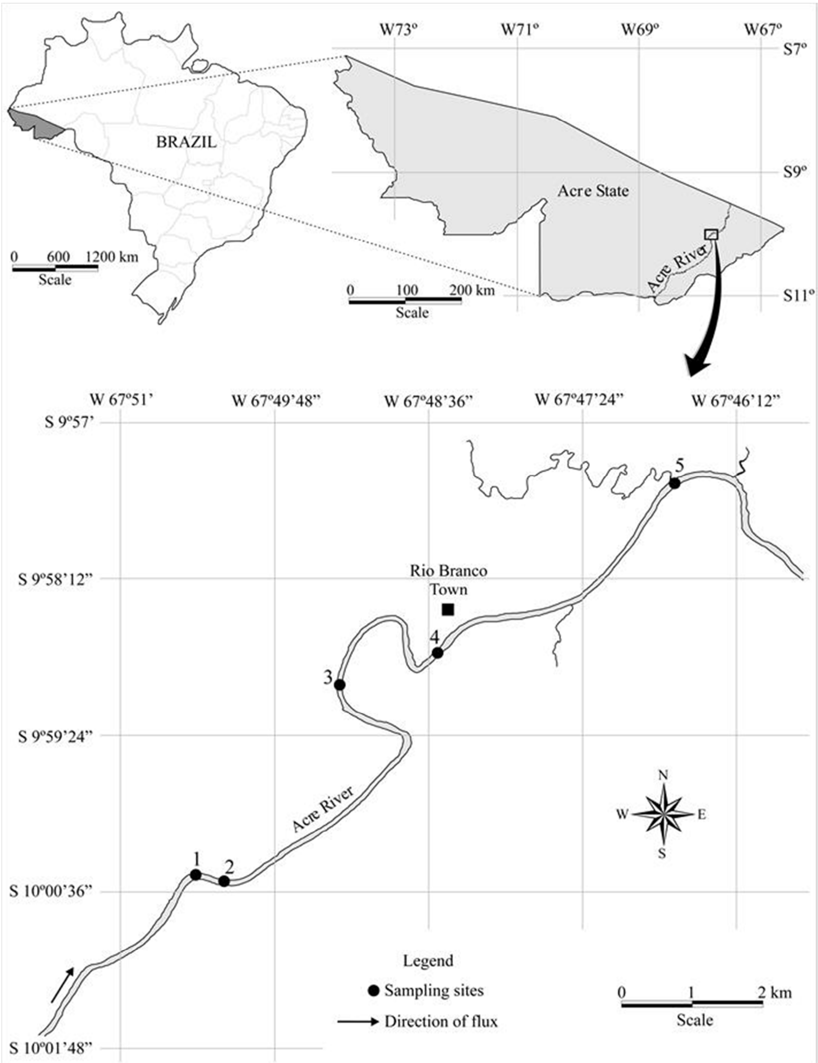

Figure 1. Location of sampling sites in Acre River: 1 (upstream of the Water Treatment Plant – WTP), 2 (downstream of the WTP), 3 (output of domestic waste most densely populated area of Rio Branco), 4 (location of recreational Gameleira) and 5 (mouth of the San Francisco stream). Adapted from (10).

To explain the dynamics of some limnological variables, were used the data on the water quota and the Acre river flow, obtained from the National Water Agency (19), and the rainfall index obtained from the Meteorological Station of the Federal University of Acre, UFAC.

Statistical treatment data was done descriptively and calculated Kendall's concordance coefficient (W) to determine agreement degree between bathing and WQI values, hydrological periods and sampling sites (20). Descriptive and exploratory univariate analysis was performed using the software Bio Estat 2.0 (21). As a measure of central tendency was used the arithmetic mean, and a measure of dispersion, the standard error and Pearson variation coefficient.

Principal Component Analysis (PCA) was performed from the covariance matrices transformed into log (x + 1) using the software PC-ORD for Windows, version 3.11 (22), to order the hydrological periods in relation to the studied variables in order to compare the different sample units.

RESULTS AND DISCUSSION

Table 1 summarizes the limnological conditions of sampling sites and classification of water quality.

Kendall's concordance coefficient (W = 10.85, df = 4, p = 0.0000) revealed that the WQI values show good quality in sampling sites 1 and 2 for the entire study period, and seasonality did not alter the WQI general classification (W = 6.26, df = 3, p = 0.0000). The low fecal coliforms levels at these sites were good water quality indicators (Table 1).

WQI values and water classification in sites 1 and 2 are in line with other premises used for public supply in Brazil, for example, Rivers Paraubebas and Mucurupi (PA), urban rivers with regular water quality (23, 24). Sites 3, 4 and 5. showed low WQI, high TN, TP, fecal coliforms and BOD values. High pollution condition in site 3 was related to the input of domestic effluents. Site 5 corresponds to the mouth of San Francisco stream, which runs through many neighborhoods of Rio Branco, transporting large wastewater pollutant load to the River. According to WQI values, it was found that the nearest sites of the urban area (3, 4 and 5) had the lowest WQI values and, hence, the worst water quality (Table 1).

Table 1. Mean values of pH, dissolved oxygen (DO), turbidity (Turb.), water temperature (Temp.), total nitrogen (TN), total phosphorus (TP), biochemical oxygen demand (BOD), total solids (TS), fecal coliforms (FC), water quality index (WQI) and bathing to an urban Acre River stretch, in Dry (S), Flood (E), Full (C) and Ebb (V) period.

Periods	Sites	pH	DO ($mg.L^{-1}$)	Turb. (UNT)	Temp. (°C)	TN ($\mu g.L^{-1}$)	TP ($\mu g.L^{-1}$)	BOD ($mg.L^{-1}$)	TS ($mg.L^{-1}$)	FC ($MP.100\ mL^{-1}$)	WQI	Bathing classification
DRY (S)	1S	7,8	5,1	82	29,2	1674	11	4,9	205	180	59	Good
	2S	7,2	5,3	113	29,2	2064	10	5,0	232	297	54	Good
	3S	7,7	5,2	81	29,3	2007	9	7,6	181	6633	48	Regular
	4S	7,7	5,1	79	29,3	1563	10	6,3	182	2307	51	Regular
	5S	7,5	4,8	79	29,3	1881	23	8,4	204	4467	50	Regular
FLOOD (E)	1E	6,8	6,4	450	28,0	1759	20	1,7	426	41	55	Good
	2E	6,6	6,4	501	28,0	1671	26	1,8	469	55	53	Good
	3E	6,8	6,4	488	28,0	1705	39	2,7	485	1577	45	Regular
	4E	6,7	6,4	485	28,0	1643	30	1,9	478	687	48	Regular
	5E	6,6	6,5	368	27,5	1709	35	2,5	412	3917	44	Regular
FULL (C)	1C	6,4	6,6	227	27,8	1233	11	1,7	303	30	56	Good
	2C	6,5	6,5	233	27,8	1377	15	2,9	359	27	54	Good
	3C	6,5	6,5	250	27,8	1370	20	3,3	339	1120	47	Regular
	4C	6,3	6,5	230	27,9	1317	23	2,1	341	560	40	Regular
	5C	6,1	6,5	211	27,5	1351	20	2,8	325	3607	45	Regular
EBB (V)	1V	7,5	7,2	77	28,1	945	15	4,6	197	348	63	Good
	2V	7,0	7,5	82	28,2	807	15	3,5	186	314	62	Good
	3V	6,9	7,8	96	28,4	1168	16	5,6	172	9200	49	Regular
	4V	6,7	8,1	72	28,4	961	15	4,3	172	8013	51	Regular
	5V	6,7	8,1	69	28,4	1515	15	5,6	178	8400	51	Regular

Regular qualifity for the site 4 was recorded during the low water although high values of fecal coliforms are possibly related to the high DO values, low turbidity and low total solids values (Table 1). A study of Açu River stretch (RN), which, also, was influenced by urban activities, agricultural and industrial equipment of all sizes, found WQI values ranked as the River ranging from good to excellent. The authors attributed this classification to low turbidity values (maximum of 51.5 NTU) and fecal coliforms (maximum NMP/100ml: 1800) (25).

In the Uba River (MG), it was found WQI values of 74 for the spring and 37 for the urban stretch located in the central city of Uba (MG), which receives effluents from wood furniture, the main industrial activity city (6). In the Acre River, the WQI also proved as a good indicator to show the water quality in the stretch studied.

BOD stands out as an indicator of water quality, it is used to express the amount of pollution produced by biologically oxidizable organic matter, depicting the amount of oxygen required to stabilize, through biochemical processes, the carbonaceous organic matter. Moreover, it is an indirect indication of biodegradable organic carbon and higher the value of BOD is the worst water quality (26). In dry and ebb periods the highest BOD values were observed, in Acre River, the highest BOD values and in flood and full the lowest values (Table 1). The improvement in water quality with respect to BOD, during periods of flood and full, reveals an increase in self-purification capacity of the river during this period due to dilution with rain water, assimilating some of their organic loads and preventing serious damage to water quality (26).

This capacity for river self-purification during high water, was also observed for Ipojuca River, one of the main Rivers of the state of Pernambuco, whose waters are used for public supply, receive domestic sewage, agro-industrial and industrial. During the dry period, the Ipojuca River water quality decreased and recorded BOD of 96.0 mg L^{-1}, while in the full BOD fell to 2.0 mg L^{-1} indicating that the Ipojuca River organic load exceeded its capacity for self-purification in the dry period (27).

Of the samples analyzed in the Acre River, only five exceeded the maximum BOD established for Class II streams (Table 1). Sites 3 and 5 were characterized by intense human activity, as they receive big load of domestic sewage without any sanitary treatment. Sewage treatment plants and large urban concentrations, exerted a strong influence on the high BOD values found on sites 3 and 5, which showed the largest pollution from such locations as reflected in low WQI values. An inverse values between the BOD values and WQI, except for sites 4 and 5 during the full period was observed (Figure 2).

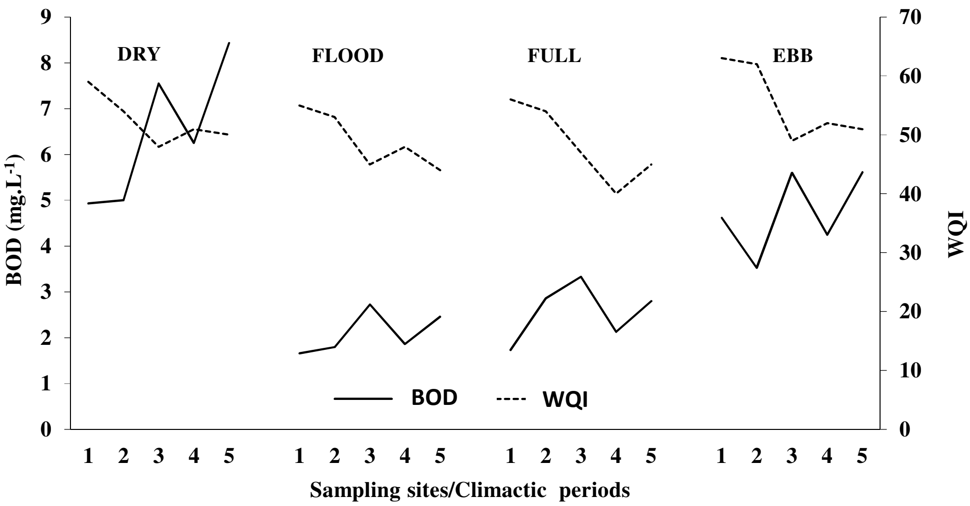

Figure 2. Water Quality Index (WQI) and Biochemical Oxygen Demand (BOD) distribution pattern along an urban stretch of the Acre River, in dry (Sep/04), flood (Dec/04), full (Mar/05) and ebb (Jun/05) periods.

Ao analisarem-se a escolaridade dos According to the bathing criteria established by (15), using the fecal coliforms presence, the sites 1 and 2 were maintained under conditions suitable for bathing, maintaining levels of excellent to very good, contrasting to the sites 3 and 5 who remained unfit throughout the study period (Table 1).

High fecal coliforms contamination in sites 3 and 5 it was due to the same location conditions of the sites. Site 3 is located at an effluent and sewage point, and site 5 at the mouth of the São Francisco stream that receives fresh domestic sewage from neighborhoods located in its hydrographic basin. Fresh domestic sewage has no previous treatment before being flushed in the São Francisco stream, being the main responsible for the condition of pollution or contamination in this point of the Acre River. The site 5 pollution was confirmed, also, by higher values for BOD, TN and TP indicating water degradation.

Hydrological influence is evident on site 4, practical place of leisure, whose waters are suitable for bathing only in time of flood and filled with fecal coliform values of about 3 to 14 times lower in relation to drought and low water (Table 1). The decrease of fecal coliforms and improvement of water quality during high water shows the flood pulse influence on the fecal coliforms density in the river stretch studied, showing that the flood pulse acts directly on the water quality. These effects was, also, observed for the Cuiaba River (MT), whose mean values of fecal coliforms from 1987 to 2000 in periods of dry and full, were differed (28).

The principal component analysis, carried out jointly to order hydrological periods and environmental variables presented in its first three axes, explain 88,7% % of the total data variability (Table 2).

Table 2. Pearson and Kendall's correlation coefficients between physical, chemical and biological variables and the first three axes of ordination in the principal component analysis determined for an urban stretch of the Rio Acre in dry (S), flood (E), full (C) and ebb (V) period.

	Main Components		
Variable	**Axis 1**	**Axis 2**	**Axis 3**
pH	**0,814**	0,361	-0,194
DO	-0,290	**-0,878**	0,188
Turb	**-0,877**	0,375	-0,069
Temp	**0,865**	0,421	0,009
TN	0,076	**0,916**	0,175
TP	**-0,750**	0,287	0,319
BOD	**0,899**	0,158	-0,326
TS	**-0,909**	0,383	0,086
FC	0,373	-0,294	**0,833**
WQI	0,405	-0,301	**-0,770**
Explicability	**47,7%**	**24,9%**	**16,1%**

Figure 3 shows that the distribution of sampling units was based on the data temporal variation (dry and full) and the system was discriminated against on the highest values recorded for environmental variables. Therefore, axis 1 represented the seasonality.

In axis 1, the flood and full sampling units were positioned on the negative side, were associated with high total solids (TS), total phosphorus (TP) and turbidity (Turb) values, while the dry and ebb sampling units, positioned on the positive side, were associated with high pH, water temperature and BOD values. In case of axis 2, the flood and dry sampling units positioned on the positive side, were associated with high total nitrogen (TN) values, while the ebb and full units positioned on the negative side, were associated with the high dissolved oxygen (DO) values (Figure 3A).

The sampling sites located on the positive axis, combined with NT, consist of those where this variable presented the highest values, depending on the input of allochthonous material during the full period (flow = 112.0 m^3s^{-1}) and concentration in the aqueous medium during the dry period (flow = 24.4 m^3s^{-1}). On the other side, sampling units located on the negative axis, associated with OD, consist of those where this variable presented the highest values, possibly due to the turbulent flow of water at high water (flow = 551.0 m^3s^{-1}) (19).

The water quality sampling units are detailed in the axis 3, where fecal coliforms (FC) and WQI showed higher correlations (Table 2, Figure 3 B). The sampling units distribution was based on the sanitary conditions variation of the system. On the positive side of the axis are located the most polluted sampling sites, correlated with the highest values of FC and lower WQI. On the negative side are located sampling units, correlated with the highest WQI values and lower CF.

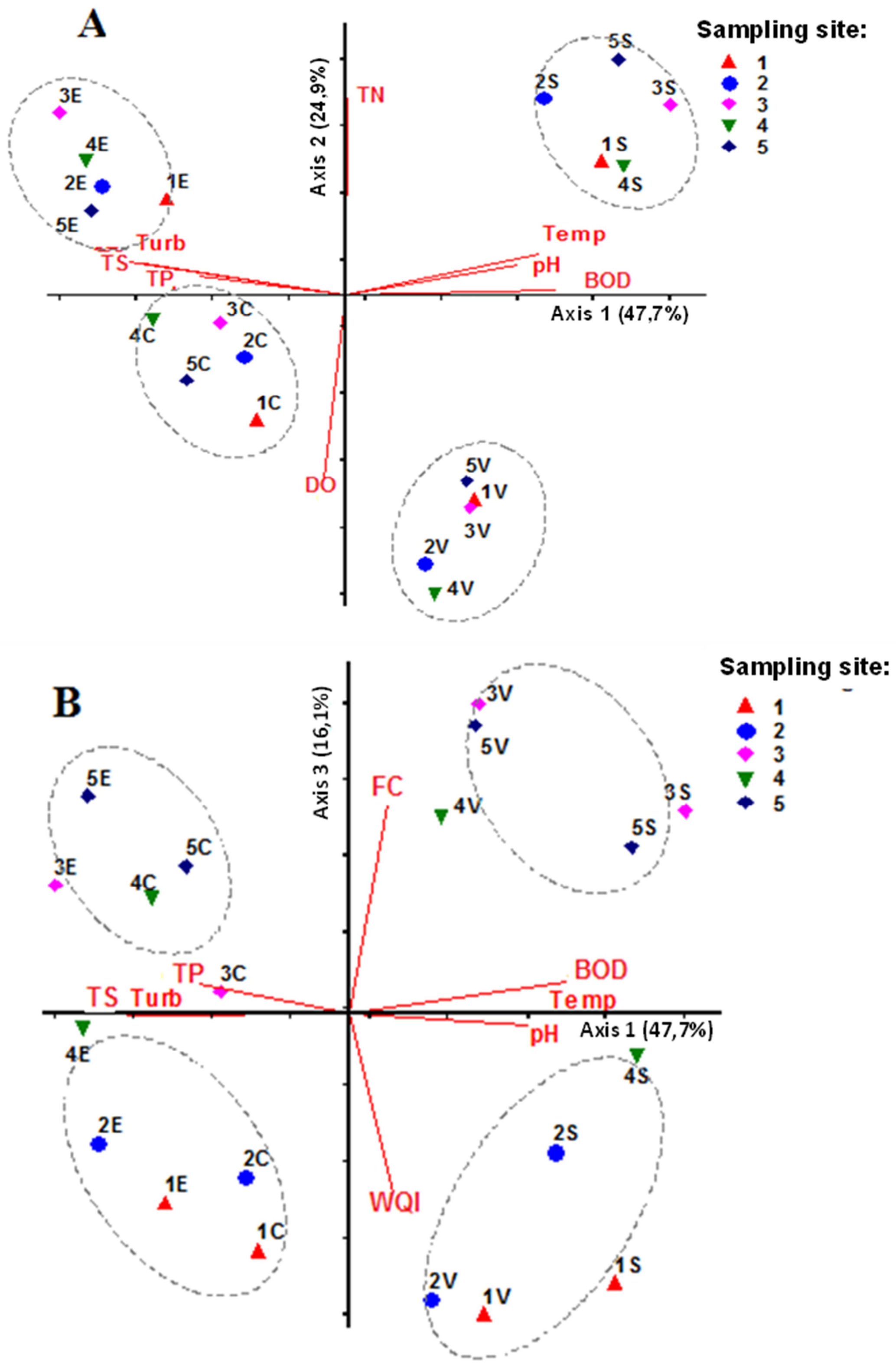

Figure 3. Ordination by PCA of the sampling units (sampling sites) and hydrological periods, depending on the physical, chemical and biological variables in an urban stretch of the Acre River. A) Axis 1 x Axis 2, B) Axis 1 x Axis 3. Sampling sites follow the sequence: 1, 2, 3, 4, 5 and climatic periods: S = dry, E = flood, C = full, V = ebb.

CONCLUSION

WQI application showed that the Acre River water falls into classes ranging from regular to good. However, it was not efficient to reveal the water quality for the site 4, at the ebb, and for the site 2, at the full, when the

WQI revealed regular quality, even compared to the high values of total phosphorus.

The Acre River urbanized stretch corresponds to the sites 3 and 4 of regular classification. This classification was due to the high density of fecal coliforms in 75% of samples having values above 1000 NMP 100 mL^{-1}. Thus the main factor force on the water quality is the fresh sewage discharge into the river. The site 4 is the most widely used for leisure and recreation. In this study, it was considered suitable for bathing in the flood and in full period due to dilution inherent in these periods and inappropriate in the ebb and dry period due to organic matter concentration.

To address this problem, it is extremely important to adopt policies and implement public health and sanitation, involving not only an urban stretch of the Rio Acre, but the extent of its entire watershed.

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