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Water quality and prospects for revitalization of an urban stream in Recife, Brazil

The urbanization of Recife characterized an occupation of the Capibaribe River banks and its tributaries. This caused the grounding, rectification and degradation of several streams. Thus, this paper presents a diagnosis of the Cavouco stream water quality and suggests measures for its restoration. The collections were performed between 2016 and 2017 in three sampling points. Analysis adopted the Standard Methods for the Examination of Water and Wastewater and calculated the Water Quality Index (WQI). A correlation test between the parameters was applied to understand the phenomenon. Actions to revitalize it followed the European Union Water Framework Directive. The WQI of the Cavouco stream had a good presentation in the small lake zone; it was poor in the Federal University (UFPE) region and awful in the Caxangá Avenue section. Dissolved Oxygen (OD) concentration was negatively correlated with Biochemical Oxygen Demand (BOD), decreasing from upstream to downstream. Water quality degradation is associated with untreated sewage discharge along the stream. The proposal to its recovery is to collect and treat domestic sewage, remove irregular housing, restore the riparian forest, control erosion, create linear parks and search for governance mechanisms with public participation. The proposed interventions are fundamental for the restoration of Cavouco's ecological potential, with improved water quality and reduced anthropogenic pressures.

Keywords: Water Quality Index; WQI; Urban Streams; Water Framework Directive.

Qualidade da água e perspectivas de revitalização de um riacho urbano no Recife, Brasil

aterramento, retificação e degradação de inúmeros riachos. Neste contexto, este artigo apresenta um diagnóstico da qualidade da água do riacho do Cavouco e indica medidas para a sua revitalização. As coletas foram realizadas entre os anos de 2016 e 2017 em três pontos de amostragens. As análises seguiram o Standard Methods for the Examination of Water and Wastewater e foi calculado o Índice de Qualidade da Água (IQA). Um teste de correlação entre os parâmetros foi aplicado para compreender o fenômeno. As ações de revitalização seguiram a Diretiva Quadro da Água da União Europeia. O IQA do riacho do Cavouco apresentou bom no trecho do laguinho, ruim no trecho UFPE e péssimo no trecho Caxangá. A concentração de Oxigênio Dissolvido (OD) apresentou correlação negativa com Demanda Bioquímica de Oxigênio (DBO), diminuindo de montante para jusante. A degradação da qualidade da água está associada ao lançamento de esgoto sem tratamento ao longo do riacho. Propõe-se para a sua revitalização, a coleta e tratamento do esgoto doméstico, retirada de moradias irregulares, recomposição da mata ciliar, controle de erosão, criação de parques lineares e a busca de mecanismos de governança com participação da população. As intervenções propostas são fundamentais para o reestabelecimento do potencial ecológico do Cavouco, com melhoria da qualidade da água e redução das pressões antrópicas.

Palavras-chave: Índice de Qualidade da Água; IQA; Riachos urbanos; Diretiva Quadro da Água.

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INTRODUCTION

Along with the development of cities, the occupation of riverbanks also advances. As they are lower areas and susceptible to flooding, they are land more undervalued by the real estate industry and more occupied by people in economic vulnerability (FONSECA et al., 2014; FIA et al., 2015). In this competition for urban spaces, watercourses have grounded and often rectified to compose drainage basins. These structures increase the flow of water, but it causes flooding downstream (TUCCI, 2013).

A further degradation cause of rivers in urban regions is the disposal of solid waste and fresh sewage. The absence or precarious nature of public sanitation systems in big and small cities has caused negative and often irreversible impacts on watercourses. The organic material, in the sewage, when thrown into the river, starts the decomposition process, causing the consumption of dissolved oxygen (DO) in the water. Without DO, rivers lose aerobic marine life, made up of fish and other organisms. In addition, the proliferation of diseases is another worrying aspect (KANG et al., 2010; VON SPERLING, 2014).

Unfortunately, the spatial configuration pattern of *Recife*, in the State of *Pernambuco*, has turned its back on the natural environments, part of the urban landscape. Take a glance at the transformation of weak ecosystems such as mangroves, forests, and estuaries into buildings, such as the *Capibaribe* River basin. Some streams in *Recife* had grounded or piping sections for rainwater drainage (VON SPERLING, 2014). The basic sanitation system is insufficient, with only 42% of domestic sewage collected and treated. It releases the remaining amount fresh in the watercourses that cross the city.

This paper presents an evaluation of water quality and shows measures for the revitalization of the *Cavouco* stream, a tributary of the *Capibaribe* River, in *Recife*. It bases such proposals on the conception of green and blue infrastructure and on the guidelines of the European Union Water Framework Directive (WFD), which adopts an ecosystem approach to ensure that the water bodies reach a state of minimal degradation (EC, 2000). The proposed interventions are essential for restoring the ecological potential of the *Cavouco*, improving water quality and reducing anthropogenic pressures.

MATERIALS AND METHODS

Characterization of the study area

Cavouco stream is a tributary of the lower *Capibaribe* right bank; it has around 18 ft of extension, around 2.6 sq yd of drainage area and around 0.00488 ft of average slope (CABRAL et al., 2014). Its source is in the Federal University of *Pernambuco* (UFPE). It is called *Laguinho* and runs through the neighborhoods of *Várzea, Cidade Universitária, Engenho do Meio, Cordeiro and Iputinga*, where it flows into the *Capibaribe* river.

Right after its source, the stream is struggling with the effects of urbanization with the strangulation of its gutter; the houses built over its riverbed; and the disposal of untreated domestic sewage. When entering the UFPE area again, it has a region with no structural intervention and surrounding vegetation. Starting from the Center for Technology and Geosciences - CTG to *Caxangá* Avenue, concrete walls pipe it.

Thereafter, it has clogged by irregular housing and solid waste in the final section of the *Capibaribe* river mouth.

Water quality analysis

These are three selected collection points based on the use and occupation of the soil and the *Cavouco* stream pipes: point 1 in the small lake of UFPE (PC1), where its source is; point 2 collected inside the UFPE (PC2); and the third point (PC3) at the intersection of *Caxangá* Avenue. The collection points are available on the map in image 1.

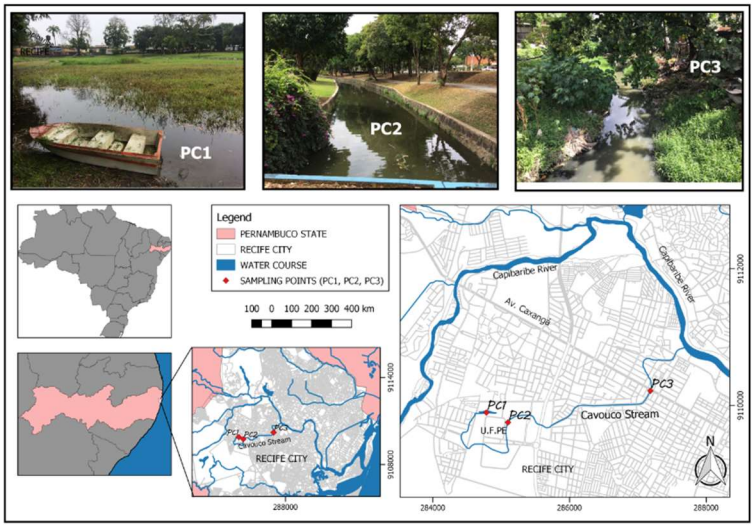

Image 1: Location of the collection points in the *Cavouco* stream, *Recife-PE.*

There were two surface water collections in May (rainy period) and August (dry period) of 2016 and six collections in 2017, in January and April (dry period), June and August (rainy period) and October and December (dry period), according to rainfall data from the National Institute of Meteorology (INMET, 2018).

They based the collection of water samples on the national guidelines for the collection and preservation of samples (CETESB, 2018). They collected the samples using a bucket of stainless steel at a depth of 20-30 cm from the surface. Afterwards, they placed them in specific storage containers, sterilized, identified and packaged in a thermal box with ice and carried to the laboratory for analysis.

Prof. Adaucto da Silva Teixeira laboratory analyzed the water quality, from the State Environmental Agency (CPRH), according to the Standard Methods for the Examination of Water and Wastewater (APHA, 2012). The analyzed parameters were: Temperature, pH, Turbidity, Ammonia (NH4+), Total Solids (TS), Phosphorus (P), Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD) and Thermotolerant Coliforms (TtC).

They gathered the results of the water quality analyses by date of collection and placed in the order from source to mouth, for a better display of the effects of urbanization. They analyzed the data with descriptive statistics, determining the median and correlation test of Person, using the statistical software, version 6.1, and created the graphs using the same software.

Pearson's correlation coefficient (r) or product-moment correlation coefficient or Pearson's r measures the degree of linear correlation between two quantitative variables. It is a non-dimensional index with values between -1.0 and 1.0, which reflects the intensity of a linear relationship between two sets of data (Larson & Farber, 2010). They tested the parameters to verify the correlation described in the literature. The Water Quality Index (WQI) calculates the weighted production of the nine parameters they will analyze. They use the following formula in the Equation 1:

$$\mathrm{WQI} = \prod_{i=1}^{n} \mathrm{qi}^{\mathrm{Wi}} \qquad (1)$$

WQI: Water Quality Index, a number between 0 and 100; qi: quality of the i-th parameter, a number between 0 and 100, obtained from the "average quality change curve", according to its concentration or measurement and, wi: weight corresponding to the i-th parameter, a number between 0 and 1, assigned according to its importance for the overall quality conformation, where: n: number of variables included in the WQI calculation.

Based on this calculation, it is possible to establish the quality of the raw water, recommended by WQI, on a scale from 0 to 100: 80 < WQI ≤ 100 (EXCELLENT); 52 < WQI ≤ 79 (GOOD); 37 < WQI ≤ 51 (AVERAGE); 20 < WQI ≤ 36 (POOR); e 0 < WQI ≤ 19 (TERRIBLE) (VON SPERLING, 2014).

Revitalization measures

They based the revitalization measures proposal for the *Cavouco* stream on a bibliographic and documentary review. The European Union Water Framework Directive (EC, 2000) and the recommendations of the Urban River Basin Enhancement Methods, a group created to spread information on river revitalization in Europe (URBEM, 2004), guided this research.

RESULTS AND DISCUSSION

Current water quality conditions of the *Cavouco* stream

Table 1 shows the results of each parameter, analyzed and categorized according to the dry and rainy seasons and the total data between 2016 and 2017. They took the median of the values to represent each collection point.

Table 1: Water quality data of the *Cavouco* stream in the dry and rainy seasons and the sum of data from 2016 to 2017.

Parameter	Dry Season			Rainy Season			2016-2017		
	PC1	PC2	PC3	PC1	PC2	PC3	PC1	PC2	PC3
Temperature (ºC)	29	30	29	28	28	29	28,2	29,1	29
pH	6,7	7,3	7,1	6,8	7,0	7,0	6,75	7,25	7,5
Turbidity (NTU)	15	10	20	6,5	15	15	8,25	15	17,5
Ammonia (mg L^{-1})	0,2	11	14,9	0,39	11,9	11,7	0,52	11,45	14,25
Phosphate (mg L^{-1})	0,88	3,36	3,04	0,46	1,91	2,16	0,67	2,05	2,55
Total Dissolved Solids (mg L^{-1})	385, 9	428, 8	501, 1	45,9 6	444, 2	498, 4	61,5	430,1 4	499,8 2
DO (mg L)	7,8	3,5	0,5	6,9	3,9	1,5	7,35	3,7	0,6
BOD (mg L)	7,6	11	33,6	6,4	18,4	24,5	7,0	14,7	32,5
Coliforms (avg/100mL.10^3)	92	160	160	2,3	160	160	76,5	160	160

The temperature and pH values found for the Cavouco stream showed no significant changes among the collection points and the seasons analyzed. Oliveira et al. (2013) also found pH values between 6 and 9 for the Cavouco stream. These values corroborate the study by Alves et al. (2017) at the Abóboras stream,

Rio Verde, Goiás, São João stream in Porto Nacional, Tocantins. The disposal of untreated sewage in the stream has little impact on the pH, because this wastewater has this parameter ranging from 6.89 to 8.47, according to studies by Monaco et al. (2014).

The turbidity presented a growth from upstream to downstream in the studied points. The values found agree with those of Araújo et al. (2013), which were 3 to 40 NTU. They assumed that the disposal of sewage contributes to concentrate suspended solids in the *Cavouco* stream. According to Libânio (2016), the increase in turbidity changes the water lighting conditions and the range of light radiation, affecting the photosynthesis and the growth of marine plants and plankton.

The ammonia concentration did not show significant variation between the rainy and dry seasons. Araújo et al. (2013) found for the *Cavouco* stream, in 2012 and 2013, the ammonia concentration ranging from 0.5 to 1.7 mg L^{-1} and in line with the trend of increasing from upstream to downstream. For watercourses with the pH below 8, almost all the ammonia is in the ionized form (NH^{4+}) (LIBÂNIO, 2016).

They associate the high concentrations of ammonia and phosphate in water with the release of untreated household waste that results in reducing dissolved oxygen (RAMIREZ et al., 2014; FIA et al., 2015; ZHANG et al., 2018). The consumption of DO happens in the nitrification and proliferation of algae, causing the phenomenon of eutrophication (DODDS, 2006). The disposal of fresh sewage highlights the high concentrations of Biochemical Oxygen Demand, and low from DO, across the *Cavouco* stream, as shown in images 2a and 2b.

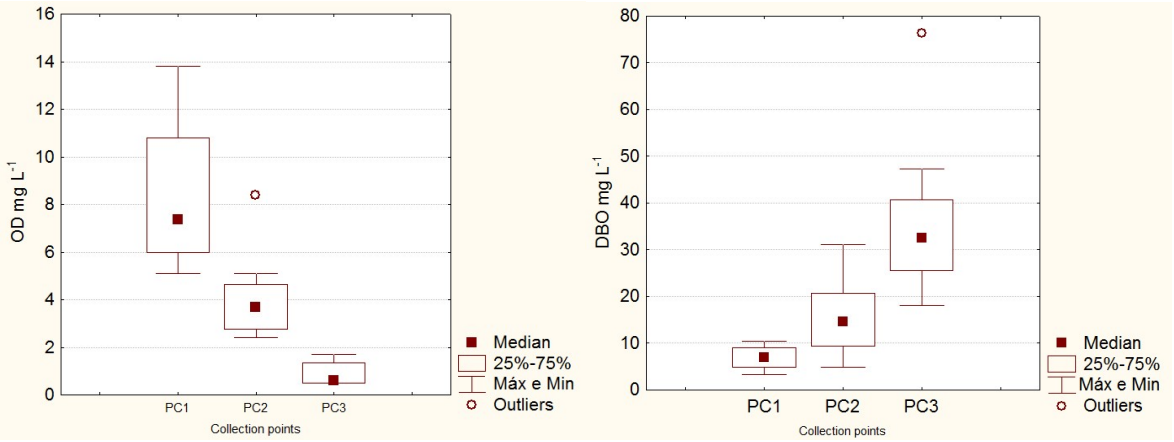

Image 2a. Dissolved Oxygen (mg L^{-1}) of the *Cavouco* stream (2016-2017)
Image 2b. Biochemical Oxygen Demand (mg L^{-1}) of the *Cavouco* Stream (2016-2017)

Araújo et al. (2013) when analyzing the dissolved oxygen of the *Cavouco* stream in five points in the UFPE, found the values of 5 and 7.5 mg L^{-1} for the small lake. The most downstream points presented values ranging from 1 to 4 mg L^{-1}. Costa *et al.* also found low values at these points, 0 to 3.8 mg L^{-1}, from 2008 to 2012 (COSTA et al., 2013).

Despite the little water flow in the small lake of UFPE, they have found great values of dissolved oxygen. In lakes and reservoirs, the concentration of DO exceeds that of saturation in days of intense photosynthetic work of the algae and marine plants (LIBÂNIO, 2016). The eutrophication waters (nutrient-rich) may present oxygen concentrations greater than 10 mg L^{-1}, known as supersaturation. This effect

disguises the evaluation of the level of water pollution, when based on the concentration of dissolved oxygen, requiring analysis of the other parameters.

Silva et al. (2001) also found in the *Cavouco* stream, in the section of UFPE, greater concentrations of BOD in the dry season, ranging from 38 to 83 mg L^{-1}, and for the rainy season, from 29.5 to 35 mg L^{-1}(SILVA et al., 2001). Costa et al. (2013). established the BOD in *Cavouco* in 2008, 2011 and 2012. At the CTG bridge point, the values were 60, 90 and 28 mg L^{-1}. Dalmas et al. (2015) associated the high concentrations of BOD and thermotolerant coliforms, found in the urban stretches of the state rivers, to the domestic sewage discharge.

The values of thermotolerant coliforms for the *Cavouco* stream showed high values at points PC2 and PC3. Silva et al. (2001) analyzed the *Cavouco* stream, in the UFPE section, and found values of thermotolerant coliforms ranging from 0.4 to 1600 x 105 avg/100 mL in the dry season and from 0.4 to 24 x 105 avg/100 mL in the rainy season.

Correlation test

The correlation test showed a very strong correlation between BOD and turbidity (0.907), and a strong correlation with ammonia (0.727), in the dry season. Phosphate also showed a strong correlation with BOD in the rainy season (0.872). They found moderate relationships between BOD, coliforms (0.642) and conductivity (0.719). They established negative correlations with Dissolved Oxygen both in the dry (-0.680) and rainy seasons (-0.646).

The test validates the assumptions that the high concentration of Biochemical Oxygen Demand in highly degraded water bodies is associated with the disposal of untreated domestic sewage (PIVELI et al., 2006; FIA et al., 2015; VON SPERLING, 2014). The pollutant load released is composed of organic material, microorganisms, phosphates, nitrates, and other substances that lead to the consumption of dissolved oxygen from watercourses and causes effects such as the death of fish and the proliferation of algae that cause eutrophication.

Water Quality Index (WQI)

After the calculations performed for the Water Quality Index, they reached the following result: the *Cavouco* stream showed better quality in the small lake (PC1), rated as good in the rainy season and as fair in the dry season. At point PC2, they rated the water as poor in all the seasons. And at PC3, it was poor in the rainy season and terrible in the dry season. The results are in table 02.

Table 2: Water Quality Index score and classification of the *Cavouco* Stream (2016-2017)

Collection Points	2016-2017		Dry Season		Rainy Season	
	WQI	Classification	WQI	Classification	WQI	Classification
PC1	57	Good	45	Fair	62	Good
PC2	33	Poor	32	Poor	28	Poor
PC3	16	Terrible	15	Terrible	21	Poor

The water classification by the WQI of the Cavouco stream validates the results of the parameters analyzed separately. In the rainy season, the water presents a slight improvement in the WQI score, because of a dilution of the sewage released fresh. In a non-degraded watercourse, the WQI worsens in the rainy season because of the transport of solids by surface drainage, as observed by Piratoba et al. (2017) in a river in Pará.

Dalma et al. (2015) also found low IQA values in the Embu-guaçu River, metropolitan region of São Paulo. The WQI proved to be a good tool for assessing water quality since it was possible to find the interactions between the parameters in a spatial and temporal distribution as Quinatto et al. (2019) and Vieira et al. (2019) recommend.

First steps for the revitalization of the Cavouco stream

The revitalization comprises the preservation, conservation and environmental recovery of rivers, through integrated actions to improve water quality for multiple uses, offer better environmental conditions and the sustainable use of natural resources, preserve the natural areas of flooding and prevent any uses that make it unviable (PICKETT et al., 2011).

The European Union's Water Framework Directive (WFD) establishes the aim of achieving good water status, which includes surface waters, good chemical status, good ecological status, and ecological potential. For changed water bodies that are not technical, financial and ecological workable to return to their original condition, the ecological potential applies. This aim requires improving the water quality and reducing or eliminating the anthropic pressures that cause degradation (EC, 2000).

This proposal for integrating watercourses to the urban landscape, creating linear parks on its banks, has achieved satisfactory results. As much in the urban drainage as in the ecological and environmental services offered by the hydric courses and in the society's acceptance. Examples are Germany, with the Isar River; France, the Sena River; the Cheonggyencheon River in Seoul, Korea; and the Tijuco Preto River in São Paulo, Brazil (RYU et al., 2016; ROLO et al., 2017).

As the source of Cavouco (PC1) presents better water quality, with greater values of Dissolved Oxygen, which leads to the understanding that this section is in good chemical status. During the collection, they verified fish in section PC2, even with a median dissolved oxygen value of 3.7 mg L-1. This shows that the stream is still alive and highlights the possibility of revitalization.

They have already adopted measures, such as the urbanization of the Cordeiro neighborhood, constructing slopes with vegetation, bicycle, and car sidewalks and roads. This promoted the river banks usage by the population for walks and sports and contributed to raising awareness of people to adopt protective measures for this ecosystem. They installed separate wastewater treatment systems, such as at UFPE. Moving forward in the revitalization process, they should take measures to make sure the ecological potential of the Cavouco stream. The chart 1 below describes the proposed interventions, divided into 5 sections, considering the current water quality, land use and occupation, vegetation on the banks, urban drainage and transport infrastructure and the services they could offer to the population.

Chart 1: Proposed interventions of the *Cavouco* stream.

Section	Main Problems	Description of Structural Measures for Revitalization
Laguinho of UFPE	Absence of riparian forest.	Restoration of the riparian forest by planting native species of the Atlantic Forest. Revitalization of the dike to contemplate the lake.
Varzea Neighborhood	Disordered urbanization with houses on top of the bed. Domestic sewage disposal.	Expropriation of irregular buildings and relocation of the population. Dredging of sediments to extend the perimeter of the canal. Enrichment of the riparian forest with native species. Expansion of collection and treatment of domestic sewage.
UFPE	The release of chemical wastewater. Concrete piping.	Treatment of chemical and sanitary wastewater from laboratories. Restoration and enrichment of riparian forest. Creation of a park with sports and leisure infrastructure in the zone between the Technology and Geosciences Center - CTG and the Arts and Communication Center - CAC.
Cordeiro Neighborhood	Disposal of domestic sewage and solid waste.	Creation of a linear park with sports and leisure equipment, permeable paving of the roads on the banks of the stream, in the section between *General Vargas* and *Manoel Estevão da Costa* Streets. Implementation of a drainage system with a solid waste retention device. Construction of slopes in the form of a staircase. Restoration and enrichment of the riparian forest.
Iputinga Neighborhood	Disordered urbanization with houses on top of the bed. Domestic sewage disposal.	Expropriation of irregular buildings and relocation of the population. Dredging of sediments to extend the perimeter of the canal. Enrichment of the riparian forest with native species. Expansion of collection and treatment of domestic sewage. In the *Caiara* Park zone, expand the riparian forest by creating habitats for birds and mammals.

The permeable paving of marginal roads to watercourses promotes more infiltration and slow percolation in the soil. Riparian forest restoration by planting large trees intercepts up to 25% of precipitation and decreases direct soil precipitation and drainage. Staircase-shaped slopes, covered with vegetation, reduce erosion on the banks while intercepting solids and hanging material (URBEM, 2004).

However, the collection and treatment of domestic sewage is the main measure to promote the revitalization of the Cavouco stream. The Public-Private Partnership project - PPP for Sanitation in the Metropolitan Region of Recife - RMR, between the company BRK Ambiental and the Companhia Pernambucana de Saneamento - Compesa is in progress.

Started in 2013, the forecast was to increase the collection and treatment of sewage to 90% by 2025. After long delays in the schedule, in 2018 they postponed the deadline to 2037. The contract signed has a high potential for renegotiations, which can generate negative consequences such as further delays and renegotiations to follow the project.

The Cavouco Stream basin is part of the Cordeiro and Camaragibe Sanitary Sewerage System. Nowadays, these systems serve only 18.42% and 4.76% of the region. Served by the Sewage Treatment Plants - ETE Caxangá III and Abençoada por Deus. The schedule signed in the 5th additive of the PPP contract expects expanding the Cordeiro system to 50% in 2021, 55% in 2023 and 96% in 2025 (COMPESA, 2018).

The sanitation works planned for the Cavouco and Capibaribe river basins will serve a large part of the population and will improve the water quality of the watercourses and health conditions of the population, such as the Velhas River in Minas Gerais as mentioned by Rollo et al. (2017). However, the great challenge is the universalization of sanitation, as provided for in the legislation, and the guarantee of the project completion. Delays in the schedule are a major concern as they may delay the revitalization of the Cavouco and other watercourses in Recife. It can also cause a lack of credibility among the public authorities.

Besides the structural measures proposed above for the revitalization of the Cavouco stream, the non-structural measures are also important. The works cause expropriation, interdiction of roads, among other disturbances. However, a project to revitalize an urban river must consider them as spaces of environmental, social, economic and cultural opportunities. Therefore, Reynoso et al. (2010) and Pickett et al. (2011) suggest that an intersectoral action is necessary for implementing the project to take place under a synergy of actions and management of public institutions, given the complexity and diversity of the players involved.

The Water Framework Directive expects popular participation in all phases of watercourse revitalization projects. The available information, call for action and public consulting are mechanisms used to govern the project (URBEM, 2004). In this sense, Luymes and Tamminga, suggest that participation should be a double path that combines popular knowledge with scientific knowledge (LUYMES et al., 1995). Therefore, the people that will take part in positive and negative ways, direct or indirect affected, in the decision-making processes are essential to the success of the Cavouco revitalization project.

CONCLUSIONS

The uncontrolled urbanization of *Recife* over the course of its history until the most recent days has occupied more and more preserved areas such as the slopes and banks of rivers and streams. The poor urban drainage infrastructure and the collection and treatment of domestic sewage is the main cause of deteriorating the water quality of its watercourses, as of the Cavouco stream, which the high concentrations of Biochemical Oxygen Demand and of thermotolerant coliforms and low concentrations of Dissolved Oxygen confirm, compromising marine life.

Comparing the results of the climatic periods, the water quality improves in the rainy season when more water is coming into the basin, diluting the sewage, as described in the literature. Different from what happens in the non-degraded watercourse, where the rains carry solids to the bed, changing its quality. The spatial analysis showed that the water quality worsens from upstream to downstream, according to the increase in urban occupations and the release of fresh domestic sewage along the watercourse.

In the more upstream sections, which include the source (PC1) and the UFPE, the Dissolved Oxygen is in the stream that is still alive. In this way, its revitalization will become possible with the correct execution of projects such as the RMR Sanitation PPP and the *Capibaribe* Park until 2025. They need a project to adopt the proposed measures, such as the removal of irregular housing, restoration of riparian forest, erosion control and creation of linear parks, following the model adopted in other cities.

The public's participation in the entire process is essential for the success of the *Cavouco* stream revitalization. From the project conceiving, with the choice of sports and leisure equipment for the linear parks, to a good social communication program to solve conflicts to move housing and environmental awareness. They recommend the search for governance mechanisms for urban rivers, in which the local people can take part in the decisions and actions proposed to recover the quality of water and revitalize the streams of *Recife*.

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