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Water systems' revitalization: interventions adopted in aquatic ecosystems in Brazil and worldwide

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Abstract - Water bodies are key elements for the subsistence and maintenance of civilizations. However, the growing populations and theoften-adopted management models of the water resources have exerted a strong impact on these, making them unsuitable for a range of uses.In order to improve the water quality and the nearby environmental conditions, several revitalization actions of watercourses have been implemented.This work presents options of actions that can be executed and the outcome of revitalization operations that took place in watercourses in Brazil and around the world. It also presents proposals for improving aquatic systems in João Pessoa city, Paraíba, Brazil.

Keywords: *water management; environmental recovery; environmental management.*

Revitalização de sistemas aquáticos: intervenções adotadas em ecossistemas aquáticos no Brasil e no mundo

Resumo - Os corpos de água são elementos essenciais para a subsistência e manutenção das civilizações. Entretanto, o crescimento das populações e o modelo de gestão dos recursos hídricos frequentemente adotados têm exercido forte impacto sobre as reservas hídricas, tornando-as inapropriadas para diversos usos. Com o objetivo de melhorar a qualidade da água e das condições ambientais próximas, várias ações de revitalização de corpos de água veem sendo adotadas. O presente trabalho objetiva apresentar algumas ações que podem ser adotadas e experiências de revitalização de corpos de água no Brasil e no mundo, apresentando propostas para a recuperação de sistemas aquáticos do município de João Pessoa.

Palavras-chave: *Manejo Aquático; Recuperação Ambiental; Gestão Ambiental*

Revitalizacion de sistemas acuáticos: intervención adoptadas en los ecosistemas acuáticos en Brasil y el mundo

Resumen - Cuerpos de agua son esenciales para la subsistencia y el mantenimiento de las civilizaciones. Sin embargo, el crecimiento de las poblaciones y el modelo de gestión de los recursos hídricos a menudo adoptadas han ejercido un fuerte impacto sobre los recursos hídricos, que los hace inadecuados para muchos usos. Con el fin de mejorar la calidad del agua y las condiciones ambientales cercanas, se han adoptado varias medidas de revitalización de los cuerpos de agua. Este trabajo presenta algunas acciones que se pueden adoptar y experiencias de revitalización de las masas de agua en Brasil y en todo el mundo, con la presentación de propuestas para la recuperación de los sistemas acuáticos en la ciudad de João Pessoa.

Palabras clave: *Gestión Acuático; Recuperación Ambiental; Gestión Ambiental.*

Introduction

In urban areas, the rivers are important structures in the landscape construction, not only for environmental values, but also cultural and aesthetic. It can also provide improvement of the environmental conditions and quality of lifewhilst presents close relationship with the identity of the place where it inhabits and the history of the population (Cardoso & Baptista 2011; Holz 2011).

A city foundation is closely linked to the presence of water.However, Holz (2011) stated that, in general, water bodies have been disregarded in many cities' planning, being used as sanitation and drainage structures, often turning up into degraded, polluted and untreated landscapes.

The fast population growth was not complemented by adequate investment in infrastructures, mainly wastewater collection and treatment, which tends to compromise the environmental quality and water resources (Macedo & Magalhães Jr. 2011; Garcias & Afonso 2013). Furthermore, Macedo et al. (2011) pointed out the illegal occupation of the riverbanks and removal of the buffer strips and riparian vegetation, as one of the causes that most strikes the quality of water resources.

In addition to pollutants discharge, another problem related to water resources in urban areas in Brazil is the undergoing plumbing and waterproofing of riverbeds (Cardoso & Baptista 2011; Macedo & Magalhães Jr. 2011; Holz 2011). According to Cardoso & Baptista (2011), these interventions contribute to reducing the time of water residence times, increasing the drained volumes and boosting the flood phenomena.

Because of the above-mentioned interventions, many urban water bodies are in conditions that prevent its use. Hence, the unquestionable need to recover the urban water as it directly affects the quality of life: not only because the reservoirs and waterways used as water sources receive large contributions from rivers and streams that cross the cities; but also the improvement of public spaces, landscapes and the protection of ecosystems that depend on water (Holz, 2011). The objective of this study was to conduct a literature review and present actions and revitalization experiences of water bodies in Brazil and worldwide, identifying measures that could be adopted by the city of João Pessoa – PB, Brazil.

Materials and Methods

This work consists of a literature review, in which were discussed the importance, guidelines and water bodies revitalization experiences in Brazil and worldwide. From this, possible alternatives were identified that could be adopted for urban rivers in João Pessoa city, Paraíba, Brazil.

Results e Discussion

Renovation of watercourses

The recovery of urban rivers and the availability of these ecosystems' services to the cities are nowadays presented as global trends. Under various names: restoration, rehabilitation or renaturation; it aims to return good quality urban rivers to the cities (Garcias & Afonso 2013).

The Ecological Restoration Society defines restoration as the intentional modification process of one location to its natural form, through procedures and interventions that lead to restabilize the sustainability and health relationship between the natural and cultural (Riley 1998 *apud* Macedo et al. 2011).

For Silva and Pires (2007), restoring a river does not mean a return to a virgin landscape, but a sustainable development of rivers and landscapes in accordance to contemporary needs and knowledge. Besides, returning a stream to its natural shape or semi-natural is very rare as the original environmental conditions are unknown, the current hydrological conditions are almost unmanageable or even the financial constraints (Macedo et al. 2011). Therefore, Teiga et al. (2006) stated that rehabilitation attempts, where possible, the return to the ecosystem conditions previous to disturbances, considering the current cultural values. According to Macedo et al. (2011), many authors incorporate the landscape and ecological dimensions and the water quality to the river restoration perspective.

The rehabilitation of a water bodies must be performed in accordance to the particular ecosystem conditions (Teiga et al. 2006). The techniques used should consider the site-specific intervention conditions (environmental, ecological, biological, social and even political), as well as the financial amount involved in these (Coelho et al. 2009). Sometimes the best choice might be not to implement any specific intervention measures, since according to Coelho et al. (2009), the non action may be sufficient to improve the condition of the river system. However it is observed that without the mitigating of the circumstances that are impacting the water body, its improvement will not occur.

Macedo et al. (2011) stated that although some authors consider that in an advanced state of degradation and environment modification, the restoration of a river can be impractical, it should be noted its importance for small streams, which can make future interventions in impacted large rivers become economically viable.

Oliveira (2011) pointed out some difficulties to the revitalization of water courses such as the illegal coastal areas occupation, the financial resources scarceness, the areas availability, the population resistance to leave the uneven areas and the projects development that are not part of wide-ranging plans that consider sanitation in an integrated manner.

Ariver rehabilitation should include more than one technique and the execution of any project without proper analysis of the situation cannot meet the intended objectives (Coelho et al. 2009). According to the author, a river rehabilitation project must favour the river system renaturation and ensure its ecological integrity, focusing on bioengineering techniques (Coelho et al. 2009).

Sanches and Jacobi (2012) observed that, in addition to improving water quality, restoration is an attempt to readmit rivers and streams into urban landscape, recover the memory of those water bodies, connect public spaces, enhance the environmental services provided by the city rivers, without disregarding the promotion of public participation.

Parameters and guidelines for watercourses restoration

Water bodies' revitalization is a complex process, as it incorporates environmental, socioeconomic, political and institutional aspects, involves interests of various bodies such as public managers, contractors and the population directly and indirectly affected, therefore these aspects should be considered while making decisions related to the revitalization options (Oliveira 2011; Coelho 2009).

In developed countries, restoration projects have four different stages: the survey on other restoration projects to evaluate the methodologies; the detailed study of the river to be restored, so that the most appropriate methodology is applied; the implementation of the proposed intervention; and evaluating the implementation

by monitoring and equating with the targets (Macedo et al., 2011).

Teiga et al. (2006) presented other steps to be followed during water bodies rehabilitation processes: 1 - Definition of a strategy for the riverine system; 2 - Identification of the riverine system problems; 3 - Identification of the rehabilitation goals; 4 - Identification of possible solutions; 5 – Production of the rehabilitation project; 6 - Implementation and management; 7 - Monitoring ; 8 - Verification and evaluation programs; and 9 - Implementation of mitigating and corrective measures.

To Coelho (2009) and Macedo et al. (2011), a rehabilitation process should include, firstly, a justification for the intervention with the specific context of the watershed hydrogeomorphological characteristics. It is essential to characterize the situation of the hydric area. According to Coelho (2009), this process is due to: characterize water quality of the studied river; identify and characterize the use given to the banks and river water; register exploitations, dams, washing places, discharges or other public activities related to the river; and characterize the existing watershed flora and fauna, referencing indigenous species and target species, so that protective measures could be included in the project.

Another important procedure in restoration programs is to find the natural condition of the fluvial environment (using historical records) or the adoption of reference segments, whose characteristics are similar to the river system being restored (Macedo et al., 2011).

It is very important that a restoration program, especially in urban areas, includes the society at all stages of the process. Ownership is a key factor and is necessary to develop an identity relationship between the place and its inhabitants (Macedo et al, 2011; Holz, 2011), aiming the site sustainability.

Macedo et al. (2011) summarized the most common goals of waterways' restoration programs as: improving water quality by removing the pollution sources; restoration of riparian vegetation; increase and improve of physical habitats within the waterways; the passage of fish; stabilizing the banks and the river channel; and flood control.

As ecosystem service providers, interventions in urban rivers and streams should consider the interrelationship of physical, biotic and human aspects with urban rivers and streams, as central elements to ensure the sustainability of cities (Sanchez & Jacobi 2012).

Watercourses restoration examples

Several actions have been and are being developed internationally aiming to restore waterways. It is observed that in many cases the types of interventions have been adapted or enhanced in response to local needs. It is usually an ongoing process, which main goal is to improve the water quality. Table 1 shows some examples of interventions targeted to restore international waterways environments.

According to Macedo and Magalhães Jr. (2011), the approaches observed in international settings often include the detention and retention of rainwater before it reaches waterways, the collection and treatment of sewage, and the development of parks and protection areas. However, as pointed out by Garcias & Afonso (2013), many international projects are not yet effectively developed.

Table 1 - Place, observed problems and main interventions in international watercourses environments.

Place	Observed problems	Interventions
Isar (Germany)	Diffuse pollution and watercourse channeling	Removal of concrete dams, which were used as substrate to develop new habitats.
Tames (England)	Effluents discharge	STPs and incinerators installation for sludge resulting from the sewage treatment.
Seine (France)	Domestic and industrial effluents discharge; agriculture	Implementation of new STPs; proper disposal of industrial effluents.
Cheonggyencheon (Seoul)	River covering for motorway construction	Historical and cultural restoration; demolition of the concrete structure; wastewater treatment; flood control; landscaping and lighting.
Perth (Australia)	Artificial channels; effluents discharge	Concrete removal; reforestation; flood control; nutrients and pollutants removal.
Anacostia (USA)	Pollutants leaching by rain; sewage overflow in rainy seasons	Improving public cleanliness.

Source: Adapted from Garcias & Afonso (2013) and Sanches & Jacobi (2012).

In Brazil, water systems restoration interventions are incipient. Some work on the national scenario suggests the restoration of urban rivers as sanitizing, urbanistic and flood control solution, however, many are only proposals and there is no effective implementation (Macedo et al. 2011). Table 2 presents some experiences in the Brazilian scenario.

Table 2 - Place, observed problems and main interventions in national watercourses environments.

Place	Observed problems	Interventions
Das Velhas River (Minas Gerais)	NS	Environmental education; habitats reconstruction; native species planting; construction of sewage treatment plants.
Mosquito River (Minas Gerais)	Effluents discharge	Public awareness and sanitation.
Tietê River (São Paulo)	Urbanization; effluents discharge	Reduced sewage release.
São Francisco River	NS	Sewage treatment; riverbanks' recovery.
Baleares (Belo Horizonte)	NS	Punctual contention of riverbanks, restoration of riparian vegetationand creation of linear parks.

NS – Not stated

Source: Adaptedfrom Garcias & Afonso (2013) and Macedo et al. (2011).

Types of intervention

The type of intervention adopted, as already mentioned, will depend on the characteristics of the water body to be revitalized. But overall it aims to favour the river system renaturation and its ecological integrity (Coelho 2009).

According to Limeira et al. (2010), there are several specific measures that can be used to restore and protect riparian areas: retention of existing native vegetation and suppression or removal of invasive species and seeds; stabilization and re-vegetation of degraded riparian areas; control and management of water sources in coastal areas and its distribution through supply systems.

Coelho (2009) presented some of the most used river rehabilitation measures and that comply, each in their

particular area of concern, with the main objectives of a rehabilitation process. These rehabilitation measures can be observed in Table 3.

Based on these proposals some simple and inexpensive measures can be proposed for the revitalization of urban aquatic environments in João Pessoa, that enables the improvement of the water quality of these ecosystems, allowing it to provide once again some environmental services such as: increasing its ability to self clearance, allowing them to receive some pollutant load and degrade it more efficiently; and that they may recover its ichthyic fauna and other biota.

Table 3: Intervention measures adopted for water bodies' revitalization.

	Name	Description
CHANNEL INTERVENTIONS (CI)	Stone blocks in the river bed	Stones placed within the riverbed in order to create covering, shelters and to reduce the river current speed.
	Bottom panels	Submerged structures placed on the bottom of the riverbed to reduce its erosion and to promote the maintenance of the channel.
	Dam, barrage, weir	Structures made of a wide range of materials generally across the width of the channel for water retention, flow diversion for mills, water abstraction or for own supply.
	Fishway	Structures aimed to improve the upstream migration of fish.
	Silting and dredging the riverbed	Addition or removal of materials from the channel bottom. Allows the remodeling of the channel section.
BANKS AND CHANNELS INTERVENTIONS(B/CI)	Refuge cells	Cells built with heavy vegetation and stone blocks, placed in the lower bank, that provides covering and shelters for fish, increasing the organic substrate and preventing the river banks' erosion.
	Wing deflector	Stone or wood structures placed on the riverbanks that do not extend through the entire channel width, to favor the deposition of sediments and the creation of new meanders.
	Specific group of rocks on the riverbank	Stones placed at the foot of the riverbank and bottom of the river channel to increase the deposition of sediments and the dissipation of the river current energy.
	Gabions mesh –Reno mattress	Rug of stones held together by a metallic net. It can be used at the bottom of the riverbed or on the riverbank and it can be vegetated.
	Riverbed filling with tree trunks	Protects from erosion and, at the same time, increases the amount of organic substrate in the water.
	Fachina	Permeable plant structure placed at the bottom of the bank and in the channel. It can be a living fachina, a dead branches fachina or gabionade. It is natural and easily adapts to the specific requirements.
BANK INTERVENTIONS (BI)	Reprofiling the riverbanks with planting.	Slope control by decreasing the volume and weight of the lands replacing them with topsoil.
	Rock mat (riprap)	Large dimension stone sheets applied freely or in bulk on the edge of the riverbank to control the erosion.
	Introduction of live cuttings and creating terraces	Techniques that support erosion control: by introducing tall plants and deep roots that act as stakes; and creating terraces along the sidelines, where vegetation can be planted.
	Live packaging	Overlaid layers of branches and gravel, anchored by stakes
	Seeding and hydroseeding	Planting seeds mixture appropriate to the place that ensure an economic and fast solution to the riverbanks vegetation, ensuring the required moist for germination.
CHANNEL, RIVERBANK AND FLOODPLAIN INTERVENTION (CRFI)	Sedimentation basin	Temporary stacking areas off the riverbed and where water and debris settle when are swept in most critical situations.
	Lade	Built for the diversion of water flow from small dams. It should be made by impermeable walls, but with vegetative capacity, to ensure soil stability.
	Flood flow lade	Alternative channel that will be the primary diversion route in cases where the runoff water flow exceeds a certain threshold value.
	Re-meanderization	Construction of meanders to decrease the river current energy and the channel slope.
	Introduction of native species	Artificial reintroduction of aquatic and terrestrial native fauna of the rehabilitation zone that is adapted to its conditions.
	Exclusion and management of animal life	Implementation of a fence to protect the physical channel space from fauna; it applies especially in regions with animal farms.
	Riverine forest area	Tree and shrubs planting on floodplain, following the river route.

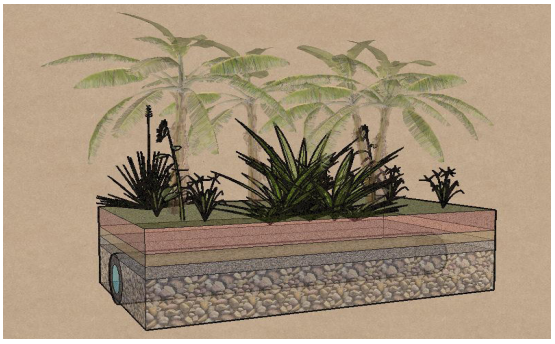
Source: Coelho (2009).

For the recovery of rivers, it should be worked not only the flow of the rivers but also the drainage basin, which passes through many neighborhoods that, in general, have no sewer system.

To minimize the problem of sewers discharges, one of the proposals observed, is the construction of ecological tanks (evapotranspiration tanks - EvapT) (Figure 1) in the riverside homes or other places where there is no sewer treatment. This technology consists of a system for sewage treatment and the recycling of nutrients in wastewater for the production of flowers and fruits (Bodens & Oliveira, 2009; Paes et al. 2014), also contributing to local landscaping.

It is also observed the need for reforestation of riparian vegetation, which will help to absorb the nutrients that are being leached into rivers. In the future, at some points where bioremediation will be applied, control the size of the trees by pruning will be needed, so there will not be shading over the water at these sites.

Figure 1 - Schematic drawing of an evapotranspiration tank.



Source: http://mundogepec.blogspot.com.br/2009/07/fossa-ecologica-tanque-de_13.html

In aquatic environments macrophytes can be used in a controlled manner. The use of such organisms is justified by its effectiveness in removing nutrients in highly eutrophized water bodies (Souza 2015). However, there is the need to control them, avoiding excessive growth, which would bring environmental problems due to the lack of light in the aquatic environment, which would facilitate degradation actions and not production, with a consequent decrease of oxygen and even anoxia of the water. Besides being necessary to control the macrophytes growth, maintenance must be carried out through removal of dead leaves, to avoid decomposition and therefore nutrients being put back into the environment.

Beside macrophytes, it can be used the biofilm, which proved to be more efficient, than the macrophyte *Eichornnia crassipes* in removing phosphorus from the water, in a natural environment (Crispim et al. 2009). Souza (2015) had showed that the presence of biofilm can improve some environmental parameters as pH, transparency and oxygen, comparing with macrophythe's effect when the system is highly eutrophied. For this, two strategies may be followed: the insertion of stones in the riverbed, which will allow the attachment of the biofilm and has the benefit of serving as a shelter and posture place for some fish species; and/or putting up plastic structures fixing the biofilm (Figure 2), as used at Dam Taperoá, which allow the attachment of biofilm on water systems that have some depth and the rocks are not efficient, as they don't receive light. This last method is suitable for the bio-treatment in the Parque Sólon de Lucena Lake, for being deeper than the rivers. The great advantage of the structures for attachment of biofilm, comparing with macrophythes, is that they do

not require cleaning maintenance, since the biofilm adhered will be fish food, and the withdrawal of it will make available space for more individuals to join or grow.

Figure 2 - Floating structures, using plastic for fixing the biofilme, apllied at Taperoá Dam. Photo: Cristina Crispim 2013.

In some rivers revitalization projects, as in the case of the Thames in London, sewer treatment measures were enough to ensured the environmental recovery and the resumption of biota that previously was almost inexistent. It is believed that with joint measures, sanitation and bioremediation, this recovery would be obtained in a shorter period of time.

Conclusion

Several studies have shown positive results on the urban rivers revitalization projects. Among them are: the improvement of living conditions and population health through the flood control and wastewater treatment; improvement of the area aesthetic and the commercial value of dwellings; improvement of the water quality; the integration of the water bodies to the urban space and the urban society dynamics; improvement of social relations as a result of communication and environmental education actions in the communities that have created a sense of citizenship clearly verified due to the positive change of habits (Oliveira 2011; Macedo and Magalhães Jr. 2011; Macedo et al 2011; Limeira et al. 2010).

Coelho (2009) emphasized that, despite the positive results expected, any intervention in the river system involves conditions that because of its specificity, should be subject to regulation and assessment. Performance indicators are important elements to aid decision-making that implicates the integrated analysis of multiple variables, with great potential for use in water resources for simplicity and comprehensiveness (Cardoso & Baptista 2012). The main objective of these indicators is to analyse the quality of the execution project, checking the suitability of the objectives and the analysis of the river system problems (Coelho 2009).

Environmental indicators (physical, chemical and biological) are probably the most developed and analysed by the scientific community as well as being the subject of extensive use (Coelho, 2009). Therefore, the following are proposed to be used as water quality indicators: Physical indicators: transparency; Chemical indicators: conductivity, pH, dissolved oxygen, DBO, DQO, orthophosphate, nitrate, nitrite and ammonium; and biological indicators: microbiological analysis (total and thermotolerant coliforms), chlorophyll-*a*, phytoplankton,

zooplankton and benthic communities and ichthyic assembly. All these parameters must be analysed before and after the restoration project implementation.

During watercourses restoration programs assessment, the social component is a necessary dimension, although according to Macedo & Magalhães Jr. (2011) it will often be disregarded. The broadening to the society participation in the approval process of restoration projects and maintenance/protection interventions is essential, as well as the appraisal of the programs efficiency by a social perspective, since the population will be largely responsible for maintaining the obtained environmental quality.

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