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SCIENTIFIC ARTICLE

Blue-Green Infrastructure in cities: climate change adaptation and reducing water pollution by pharmaceutical micropollutants

Infraestrutura Azul-Verde nas cidades: adaptação às mudanças climáticas e redução da poluição hídrica por micropoluentes farmacêuticos

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ABSTRACT: In the context of climate change, city planning needs to seek holistic solutions that, in addition to mitigating the effects of climate change, can move towards the solution of other urban environmental problems. The pollution of urban waters is a critical problem in Brazilian cities that still have a deficient sanitary infrastructure. While emerging pollutants in developed countries have already occupied a prominent place in discussions, these pollutants have not received attention in Brazil. This paper discusses using the Blue-Green Infrastructure (BGI) as a systemic solution for cities, discussing its potential to remove pharmaceutical micropollutants, its feasibility, and possible scenarios for implementation in the region of the main river basin of Curitiba city, Brazil. The first part of the paper discusses the effects of climate change on the water regime of cities, conceptualizes BGIs, and discusses pollution by pharmaceutical micropollutants as a new urban challenge. In the second part of the paper, the scenarios for implementing BGIs in Curitiba, available areas, costs, urban potentialities, and the most suitable types of plants are investigated and discussed. BGIs, with their multifunctionality and low cost, have the potential to spread across the developing world, pointing to the future of cities and urban planning.

Keywords: Water Quality Management; Blue-Green Infrastructure; Emerging Pollutants; Urban Planning; Climate Change Adaptation; Resilience Cities.

RESUMO: Em um contexto de mudanças climáticas o planejamento das cidades precisa buscar soluções holísticas, que além de mitigar os efeitos da mudança do clima, possam caminhar na direção da solução de outros problemas ambientais urbanos. A poluição das águas urbanas é um problema crítico nas cidades brasileiras que ainda apresentam uma deficitária infraestrutura sanitária. Enquanto nos países desenvolvidos os poluentes emergentes já têm ocupado lugar de destaque nas discussões, no Brasil esses poluentes ainda não têm recebido atenção. Este artigo discute a utilização da Infraestrutura Azul-Verde (BGI) como solução sistêmica para as cidades, discutindo seu potencial para remover micropoluentes farmacêuticos, sua viabilidade e possíveis cenários para implementação na região da principal bacia hidrográfica da cidade de Curitiba, Brasil. A primeira parte do artigo discute os efeitos das mudanças climáticas no regime hídrico das cidades, conceitua os BGIs e discute a poluição por micropoluentes farmacêuticos como novo desafio urbano. Na segunda parte do artigo são investigados e discutidos os cenários para a implantação de BGIs em Curitiba, áreas disponíveis, custos, potencialidades urbanas e os tipos de plantas mais adequados. Os BGIs com suas multifuncionalidades e baixo custo tem o potencial de se espalharem pelo mundo em desenvolvimento apontando para o futuro das cidades e do planejamento urbano.

Palavras-chave: Gestão da Qualidade das Águas; Infraestrutura Azul-Verde; Poluentes Emergentes; Planejamento Urbano; Adaptação as Mudanças Climáticas; Cidades Resilientes.

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1. INTRODUCTION

The growing and competing demands of society for water have increased the complexity of water management, especially in cities where water resilience is a goal. This is the case in both developed and developing countries. Climate change adds a further layer of complexity. Climate change is changing the hydrological cycle with an intensity that differs from place to place but shows the general behavior of intensifying droughts and heavy rains (MacAlister & Subramanyam, 2018). Although climate change has global causes, cities need adaptation measures to mitigate its effects. Therefore, it is necessary to implement monitoring, planning, and control measures in relation to both extreme weather (rainfall deficits and high precipitation volumes), depending on the scenarios for each region.

For developing countries such as Brazil, there are other variables that make water management challenging. Unlike much of Europe or developed countries such as Canada, the USA, and Australia, discharge of sanitary effluents into urban rivers is still common in Brazil. The developed world is already responding to new urban water quality issues such as micropollutants (Gilbert, 2012; Cunha et al., 2016), but the focus in Brazil is still on achieving universal sanitation. Therefore, in the developing world, cities need to deal with global problems such as climate change while simultaneously solving local issues such as water pollution. Efficient technologies that mitigate floods and water scarcity, improve water availability and water quality management (such as minimizing micropollutants concentration and presence) are emphasized in the plan for cities in developed countries.

In this paper, we propose a nature-based approach for the removal of pharmaceutical micropollutants from urban waters, a type of pollution for which management strategies are still lacking in the developing world. The methodological approach is new for Brazil and Latin American but perfectly feasible for any developing country where funds are tight, emphasizing the possibilities of these technologies to mitigate the challenging problem of pharmaceutical micropollutants. The object of analysis was the city of Curitiba, the capital of the Paraná state and the biggest city of southern Brazil. The paper's main objective is to discuss the applicability of Blue-Green Infrastructure (BGI) as means of supplementing water quality management systems while also providing multiple co-benefits for cities. In the first part of the paper, we present some cases of extreme weather events in cities; we conceptualize systems of BGI with an emphasis on removing micropollutants and; we outline the problem and management strategies of pharmaceutical micropollutants. In the second part of the paper, we contextualize the pharmaceutical pollution in Curitiba by its main river basin and propose possible BGI solutions. This paper discusses a new way for urban planning in Brazil already scattered for the developed world, fundamentally based on natural capital, where even controversial and challenging problems like pharmaceutical micropollutants can be mitigated with a systemic and feasible approach.

2. BACKGROUND

2.1 Climate extremes and urban water management

Climate extremes represented by heavy rains and prolonged droughts are a significant problem for cities, especially in terms of sustainable and resilient water management. In addition to quantitatively affecting local water availability for multiple human activities, they also cause substantial oscillations in the water quality, making it difficult to treat. These vulnerabilities are a reality in several countries where problems for water supply in major cities have been reported recently.

Australia is highly susceptible to flooding. Data show that, in the period from 1967 to 1999, about AU$ 314 million was spent each year to minimize its effects (Gentle et al., 2001). Comparing post-disaster expenditure, considering different climate events shows that floods were the most expensive type of natural disaster in Australia, followed by severe storms and tropical cyclones. Heavy rains are the predominant cause of floods, usually combined with other elements such as rainfall distribution and, soil imperviousness, among other factors (Ghofrani et al., 2016). Therefore, the need to prepare Australian cities for extreme weather events, such as heavy rains causing floodings, is strategic for water management in the urban context.

Droughts have also caused water rationing in large urban centers due to depleted water supply reservoirs. Three of the most recent cases are in Cape Town in South Africa, Barcelona in Spain (Martin-Ortega & Markandya, 2009), and São Paulo in Brazil (Otto et al., 2015, Zuffo, 2015, Muller, 2018). In all of these cases, the main point of discussion was whether climatic extremes could be attributed as the primary driver of these events. There is evidence of deficiencies in urban planning and water management in some cases too.

In the case of Barcelona, historical records show that the 2007-08 drought was the most severe of the century and was therefore an exceptional climatic event (Martin-Ortega & Markandya, 2009). In the specific case of São Paulo, historical precipitation data in the Southeastern region of Brazil do not demonstrate a robust temporal anomaly in the rainfall regime for the period 2014-15 (Zuffo, 2015; Otto et al., 2015), although hydrological models predicted the risk of severe drought (Muller, 2018). On the other hand, in the Northeast region of Brazil, a climatic evaluation of the period 1981-2016 showed that this region presented the most severe and prolonged drought between 2011 and 2016 (Brito et al., 2018). In Cape Town, the 2016-17 drought was indicated in 2009 by hydrological models, which pointed to the need to increase water reserves for human supply. However, authorities dismissed these recommendations (Muller, 2018). These case studies, which are three of many, show that water supply problems caused by droughts in large cities are a combination of the effects of extreme weather events and problems of city management and preparedness for climate change.

In addition to the problems related to the amount of water, whether it is excessive, causing floods, or scarce leading to shortages, extreme climatic events also cause oscillations in urban water quality by concentrating or diluting the aquatic pollutants. For example, in the São Paulo water crisis, pumping the volume near the bottom of the city's reservoirs was announced as an emergency measure (Soriano et al., 2016). This was a point of much debate by specialists since the concentration of some pollutants, mainly inorganic micropollutants such as heavy metals, could be higher near the bottom of the reservoirs. In drought events, urban rivers can also increase the concentration of pollutants by reducing their base flow, significantly increasing pollution levels.

2.2 Blue-Green Infrastructure and the environmental sustainability of cities

In developed countries that are in the “sustainable” phase of sanitation management (Tucci, 2008), there are advances in solving problems of water management with the use of systems known as Green Infrastructure (GI) or Blue-Green Infrastructure (BGI). The term BGI evolves from the Australian concept of Water Sensitive Urban Design (WSUD) and refers more particularly to “green” that temporarily turns “blue” during rain and flood events (Everett et al., 2015; O’Donnell et al., 2020). The ideas and practices related to these systems have been used for a long time, although this overarching concept is relatively new. Internationally, BGIs has been applied under various terms or programs, such as Stormwater Best Management Practices (BMPs) and Low Impact Development (LID) in the USA, Sustainable Urban Drainage System (SUDS or SuDS) in the United Kingdom, Alternative techniques (ATs) or Compensatory techniques (CTs) in France, Water Sensitive Urban Design (WSUD) in Australia, Low Impact Urban Design and Development (LIUDD) in New Zealand, ABC (Active, Beautiful and Clean) Singapore Water Program, and Sponge City Initiative in China (Fletcher et al., 2015; Liao et al., 2017). BGI “is an interconnected network of natural and designed landscape components, including water bodies and green and open spaces” (Ghofrani et al., 2017) that provide multiple functions: water purification, flood control, water storage, treatment, and wetlands for wildlife habitat, among others (Ghofrani et al., 2017; Brears, 2018). These systems are the green roofs that are numerous in some European cities, the rain gardens or bio-retention ditches common in several cities in the United States, and the various wetland systems and retention/detention basins spread across Australia’s metropolises.

The BGI systems offer natural solutions for urban water management, with costs equivalent to those of traditional systems (Lloyd et al., 2002), and important examples of their efficiency are reported in the literature: to control urban floods, such in Belgium; increased water infiltration, reduced surface runoff, decreased urban heat island effects, and coping with climate change, such in Japan (Ghofrani et al., 2017); reduction of excessive load in the drainage systems and frequent overflow events in the combined systems, forcing the discharge of sewage and rainwater directly into rivers and causing flooding, such in USA (O’Donnell et al., 2020); reduced risk of flooding, due to the inability of drainage systems to receive large volumes of precipitation, such in United Kingdom (Ellis, 2013) improvement of water quality, and ecological destination for drainage water to reduce the burden on the unit system and guarantee water security for cities, such in Australia (Wong, 2006; Liao et al., 2017). Using BGI systems to improve urban water quality can remove the most diverse aquatic pollutants (Table 1).

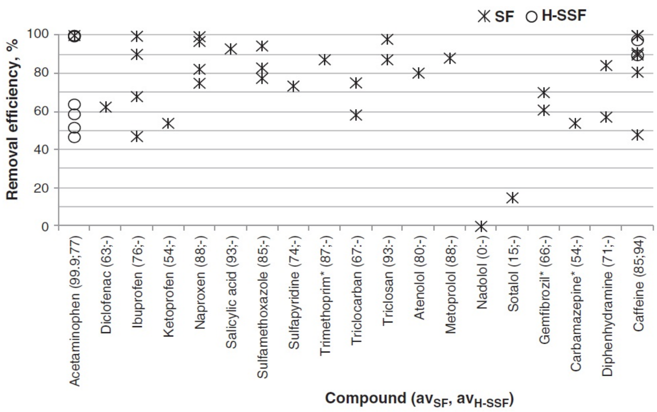
Table 1 - Relative improvement in water quality, reduction volume, and recharge performance of Green-Blue Infrastructure practices.

Green Infrastructure Practice	Quality and Quantity Benefit										
	Bacteria	Metals	Organics	Sediment	Pesticides	Nutrients	Oil and Grease	Trash	Flow rate	Volume reduction	Groundwater recharge
Bioretention cells	+++	++	++	+++	++	+++	++	+++	+++	+++	+++
Bioretention strips/swales	+++	++	++	+++	++	+++	++	+++	+++	+++	+++
Infiltration basins/swales/trenches	+++	++	++	+++	++	+++	++	+++	+++	+++	+++
Planter boxes	+++	++	++	+++	++	+++	++	+++	++	++	++
Constructed wetlands	+++	++	++	+++	++	++	+++	++	+++	++	++
Rainwater capture	++	++	++	+++	++	++	++	++	+++	+++	+++
Permeable pavement	+++	++	++	+++	++	+++	+	+	+++	+++	+++
Dry wells	+	+	+	+	+	+	+	+	+++	+++	+++

Source: adapted from USEPA (United States Environmental Protection Agency, 2013).
+++: primary benefit; ++: secondary benefit; +:little or no benefit

The use of wetlands, especially for water quality improvement, is already a well-established solution and an alternative with public acceptance (Schröder et al., 2007). Experiences of the implantation of these systems in urban water bodies are numerous. Some of these systems focus on treating waters derived from urban drainages, such as in Melbourne, Australia (Allinson et al., 2015), and the Welsh Harp Reservoir in London, England. While others also treat wastewater such as Lake Enäjärvi, Vihti in Uusimaa in Finland (Wahlroos et al., 2015), Parc du Chemin de I'lle in Nanterre in France - where there are processes of de-pollution of the Senna River - and Putrajaya Lake in the city of Putrajaya in Malaysia (Shutes, 2001). However, regarding the ability of these systems to remove emerging micropollutants, especially pharmaceuticals, the information is early because it is still the subject of recent studies (Li et al., 2014; Gorito et al., 2017) and a new problem for urban water quality management. The results of some studies that tested the effectiveness of wetlands in removing pharmaceutical products (Figure 1).

Figure 1 – Reported removal efficiencies in constructed wetlands acting as a primary step.



Source: Verlicchi & Zambello (2014)

Note: Circle = H-SSF (horizontal subsurface flow) bed, asterisk = SF (surface flow). *Negative percentage removal efficiencies reported for trimethoprim (−283%), gemfibrozil (−68%) and carbamazepine (−44%, −177%, −316%).

2.3 Pharmaceutical pollutants in urban waters and management challenges

The problem of pharmaceutical residuals in rivers and other water bodies in urban areas has been emphasized internationally because of its importance to the natural environment and public health (Fent et al., 2006; Owen & Jobling, 2012). This class of pollutants originates in sewage since, after use, they are excreted by the body in unchanged form or as metabolites and many exist as compounds that are resistant to the treatment of sewage and water (Aquino et al., 2013; Dias, 2014). Additionally, the pharmaceutical sector generates a significant part of this residual itself (Cue & Zhang, 2009).

The same wastewater produced in cities often returns to the water supply systems by the common "indirect and not planned reuse of wastewater" (Hespanhol, 2014). Once conventional water treatment systems and sewage treatment systems cannot altogether remove these compounds, the presence of traces of medical substances in supply water has been reported worldwide (Dias, 2014; Sun et al., 2015). Their presence has already been observed in drinking water in the USA, Canada, France, Spain, the Netherlands, South Korea, and China (Sun et al., 2015). In the drinking water provided in the three most populous Brazilian metropolitan areas - São Paulo, Rio de Janeiro and Belo Horizonte - significant concentrations of medical substances have also been found (Ghiselli, 2006; Gerolin, 2008; Moreira, 2008; Dias, 2014; Barcellos et al., 2019; Böger et al., 2021). Prolonged exposure to small doses of these pollutants is a potential public health problem, both directly (by water intake) and indirectly (by the presence of these compounds in urban rivers), as the adverse environmental effects of several of these residuals are proven (Bila & Dezotti, 2003; Gilbert, 2012; Cunha et al., 2016).

Among the numerous traces of medical substances in urban rivers, some drugs have attracted more attention because of their significant environmental effects, such as Diclofenac, Ethinylestradiol, Fluoxetine, and Ibuprofen (Boxall, 2012). In general, the most recurrent effects of these drugs on living organisms are acute toxicity (compound effect on mortality), chronic toxicity (compound effects on reproduction and growth), behavioral, biochemical, genetic, and histological effects over cells and tissue (Boxall, 2012). However, these effects are known only for a small group of compounds and their impacts are understood only in an isolated and non-synergistic way (Kümmerer, 2009).

For human health and environmental authorities throughout the world, two principal classes of pharmaceuticals are indicated as strategic for monitoring and reducing their concentration in natural waters: antimicrobials and hormonally active compounds (World Health Organization, 2000; Bila & Dezotti, 2003; Kümmerer, 2009). The presence of antibiotics in urban waters may be contributing to the development of resistant pathogenic bacteria. The development of bacterial resistance to antimicrobials is a significant medical issue identified by the WHO - World Health Organization (2000) and considered one of the major public health problems of the 21st century. Another paramount concern of the presence of these pollutants in the environment is their toxicity to living organisms (Locatelli, 2011). The toxicity limit of some antibiotics in the aquatic environment is relatively low, as in cases of Sulfamethoxazole (0.025 $\mu g.L^{-1}$), Erythromycin (0.010 $\mu g.L^{-1}$), Clarithromycin (0.070 $\mu g.L^{-1}$), Ciprofloxacin (0.060 $\mu g.L^{-1}$) (NOPILLS, 2015). Concerning the direct effect on public health (water intake), the hormonally active compounds have worried health authorities for their potential to cause disorders in the endocrine system of living animals (Ghiselli & Jardim, 2017) and the aquatic communities (Bila & Dezotti, 2003; Gilbert, 2012; Cunha et al., 2016).

Among the hormonally active compounds derived from pharmaceuticals, the synthetic hormone 17-α-Ethinylestradiol is the first on the list of the health authorities in Europe and North America (Owen & Jobling, 2012). The 17-α-Ethinylestradiol is an active ingredient present in almost all oral contraceptives and estrogen used in hormone replacement therapy, and is one of the most widely used pharmaceutical products in the world (Cunha et al., 2016). This compound has been commonly found in natural waters because it persists through water and wastewater treatment processes. Researchers point out that it is responsible for endocrine disruption in aquatic organisms (Gilbert, 2012). In Europe and North America, efforts have been undertaken to reduce and control this compound in waters, but little has been done in Brazil.

Several studies have pointed out the opportunities for managing pharmaceutical residuals in urban waters and involve all sectors that somehow integrate the productive chain of these products (Doerr-Macewen & Haight, 2006; Kümmerer, 2009; Metz & Ingold, 2014). In the developed world, there are several consolidated strategies such as the drug take-back program (Carazza et al., 2014), advanced sewage treatments (Doerr-Macewen & Haight, 2006; Owen & Jobling, 2013), collaborative projects for rational use and discard of pharmaceuticals (START, 2008; PILLS, 2012; NOPILLS, 2015) and monitoring efforts in waters, etc. (Cunha et al., 2016). For the waters of the large Brazilian cities (over 1 million inhabitants), the main problem is still low urban sanitation coverage or problems in the network of sewage collection that end up taking the sanitary effluents directly to the urban rivers. In Brazil just 46% of sewage is treated (SNIS, 2018).

3. CHALLENGES AND SOLUTIONS FOR CURITIBA

3.1 The context of water management and pollution by pharmaceutical residuals in Curitiba

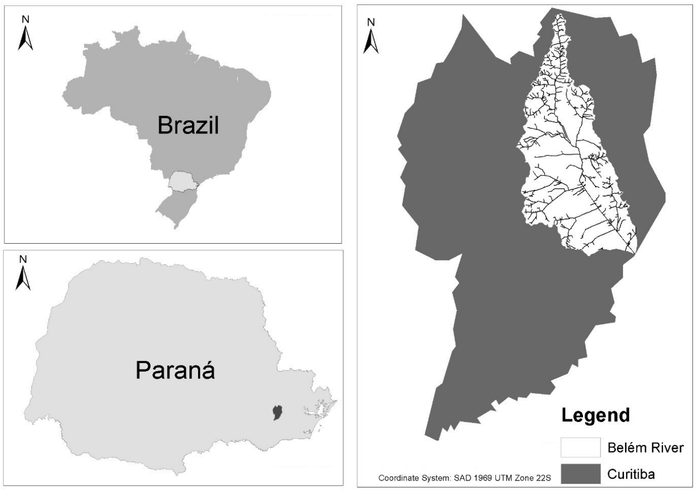
Curitiba is the eighth-most populous city in Brazil, with over 1.9 million (Instituto Brasileiro de Geografia e Estatistica, 2020). The city is known worldwide as a reference in urban planning, especially regarding the environment and urban mobility policies. Curitiba is considered sustainable and called an "ecological city" (Macedo, 2013, Mega, 2010). As far as transport is concerned, the city was the pioneer of the BRT (Bus Rapid Transit) system that is now used in many cities worldwide. As the urban management model in Brazil, the city was selected to explore the potential for innovation in management and environmental planning, such as emerging pollutants management and BGI systems.

However, in terms of urban river pollution, Curitiba is similar to other large Brazilian cities, where urban rivers have high levels of contamination by domestic sewage. Curitiba has the best basic sanitation indices among Brazilian capitals, with 94% sewage coverage, 100% water supply and 100% garbage collection (Sistema Nacional de Informações sobre Saneamento, 2018). However, the high water pollution levels in the city's urban rivers demonstrate problems in the sanitary structure (Bollmann & Edwiges, 2008; Barcellos et al., 2019; Böger et al., 2021). The sewage system of Curitiba suffers from three types of problems. The first problem is lack of connection by households despite the system being available to them, and as a result they discharge their effluents directly into the rivers. The second type is lack of coverage and therefore sewage is dumped into the drainage system or even directly into the rivers. The third type of problem is mainly related to the central part of Curitiba that has, an old sanitary network with unauthorized connections between sewerage and drainage systems, and sometimes directs the sewage together with rainwater to the rivers. The central river basin in Curitiba, the Belém River, is an excellent example of this reality.

The area of the Belém River basin is typically urban and is entirely within the municipality of Curitiba (Figure 2). It has an area of 87.85 km^2, occupying 20% of the city territory. Considering that in 2017 the population of Curitiba reached 1,908,359 inhabitants (Instituto Brasileiro de Geografia e Estatistica, 2020), the number of inhabitants of the basin of the Belém River reached about 518 thousand inhabitants. According to Lara (2014), about 43% of the properties in the basin are not correctly connected to the sewage network, which consequently reflects high levels of pollution from domestic sewage. Regarding the general water quality in the Belém River, there is a progressive degradation from the originating springs through to the mouth due to punctual and diffuse sources of pollution. About 90% of this pollution is derived from domestic sewage discharged directly to the river or drainage networks (Bollmann & Edwiges, 2008).

Due to the intensity of pollution by domestic sewage in the Belém River waters, the presence of pharmaceuticals is also significant. Table 2 shows the pharmaceutical residuals already monitored and the concentrations found in the Belém River. It is possible to observe substantial concentrations of several medical substances with environmental impacts, such as the Diclofenac, 17-α-Ethinylestradiol, 17-β-Estradiol, and Estrone. But the highlight is the synthetic hormone 17-α-Ethynylestradiol, derived from birth control pills and medications used in hormone replacement therapies. The safe concentration of this compound in natural waters, according to European toxicologists, is 0.035 ng.L^{-1} (Gilbert, 2012). A concentration 17-α-Ethynylestradiol as low as 6 ng.L^{-1} can cause irreversible damage to aquatic communities due to endocrine interference. Concentrations ranged from <48 to 5,830 ng.L^{-1} were found in the waters of the Belém River.

Figure 2 – Location of the Belém River basin.



Source: Authors, 2021.

Table 2 – Pharmaceuticals in the waters and the sediment of the Belém River.

Class	Compound	Concentration		Reference
		Water	Sediment	
		P0% - P100%	P0% - P100%	
Hormone	17β-estradiol	<25 – 20,987 ng L^{-1}	12,710 – 16,690 ng kg^{-1}	Padilha & Leitzke (2013), Ide (2014), Mizukawa (2016), Barcellos et al. (2019)
	17α-ethinyl oestradiol	<48 – 5,830 ng L^{-1}	31,650 – 33,890 ng kg^{-1}	Padilha & Leitzke (2013), Ide, (2014), Mizukawa (2016), Barcellos et al. (2019)
	Estrone	<26 – 2,420 ng L^{-1}	58,080 – 128,080 ng kg^{-1}	Padilha & Leitzke (2013), Mizukawa (2016), Barcellos et al. (2019)
Antihypertensive	Metoprolol	61.1 – 2,125.9 ng L^{-1}		Osawa et al. (2015)
	Propranolol	68.7 – 299.7 ng L^{-1}		Osawa et al. (2015)
	Nadolol	<14.1 - 30 ng L^{-1}		Osawa et al. (2015)
Anti-inflammatory	Naproxen	<9.5 - 640 ng L^{-1}		Ide (2014)
	Ketoprofen	<5.0 – 2,540 ng L^{-1}		Ide (2014)
	Ibuprofen	<31 - 729 ng L^{-1}	<1,200 ng kg^{-1}	Kramer et al. (2015)
	Diclofenac	<31 - 61 ng L^{-1}	<1,900 ng kg^{-1}	Kramer et al. (2015)
Analgesic	Paracetamol	120 - 261 ng L^{-1}	<1,260 ng kg^{-1}	Kramer et al. (2015)
	Acetylsalicylic acid	<36.1 – 8,570 ng L^{-1}		Ide (2014)
Metabolite	Salicylic acid	<33.7 – 1,550 ng L^{-1}		Ide (2014)
Lipid Regulator	Genfibrozila	<0.92 - 217 ng L^{-1}		Ide (2014)
	Fenofibrate	<0.77 - 395 ng L^{-1}		Ide (2014)
Stimulant	Caffeine	100 – 59,810 ng L^{-1}		Ide (2014)
Antibiotic	Amoxicillin	180 - 1,210 ng L^{-1}		Böger et al. (2021)
	Azithromycin	80 - 500 ng L^{-1}		Böger et al. (2021)
	Ciprofloxacin	<20 ng L^{-1}		Böger et al. (2021)
	Doxycycline	<200 ng L^{-1}		Böger et al. (2021)
	Norfloxacin	110 ng L^{-1}		Böger et al. (2021)
	Sulfamethoxazole	1,090 – 1,320 ng L^{-1}		Böger et al. (2021)
Psychotropic	Carbamazepine	209 – 856 ng L^{-1}		Böger et al. (2018)
	Diazepam	435 – 763 ng L^{-1}		Böger et al. (2018)

3.2 Blue-Green Infrastructure for the improvement of water quality rivers in Curitiba

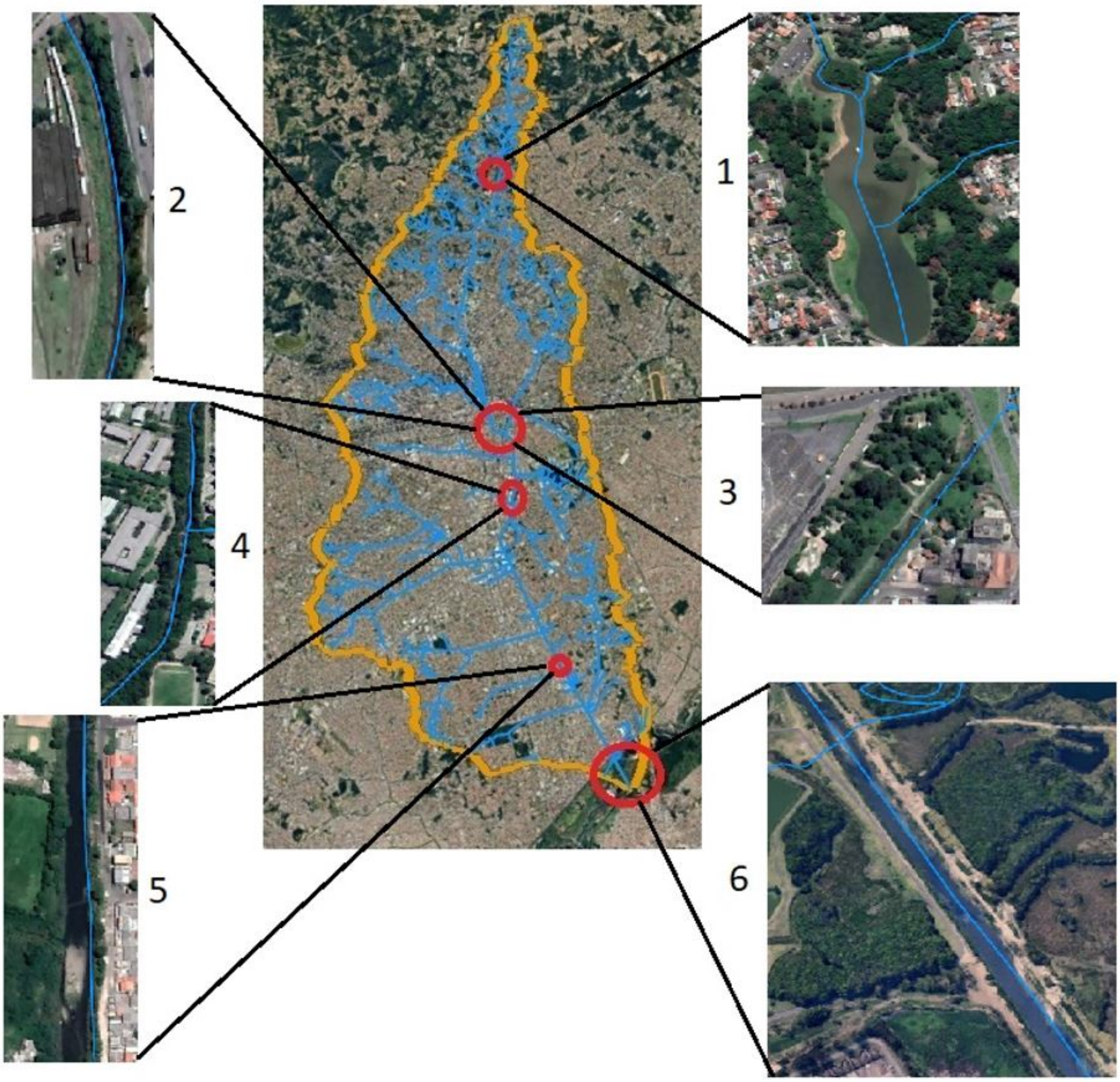
An alternative to the emerging need to reduce pharmaceuticals concentration in the Curitiba rivers is Blue-Green Infrastructure. The possibility of using these urban infrastructures to minimize water pollution would be a municipal strategy since the use and occupation of land is a municipal responsibility. Constructed wetlands can efficiently mitigate this problem and still bring many co-benefits, contributing to the mitigation of extreme climatic effects such as floods in the urban context. According to experiments reported in the scientific literature, wetlands provide the same general efficiency in removing pharmaceutical products from sewage compared to conventional treatments (Li et al., 2014; Verlicchi & Zambello, 2014). The scenario proposed here uses the Belém River basin as a case study for water management due to the wide availability of information and data about the population the river supports and its environmental condition. It is also the most representative basin in the city and has great symbolic importance to Curitiba because of its touristic, economic, and city marketing features.

Considering the problems of urban sanitary infrastructure in the central region of Curitiba, where the Belém River basin is located (Bracht, 2008; Lara, 2014), one possibility to improve the natural water quality is to implant constructed wetlands in available areas. These systems can treat the raw sewage still being directed to the river or even the heavily polluted river waters themselves. The Belém River basin already has some systems of BGI constructed to mitigate floods that also can be used to improve the water quality. But the first challenge is to identify areas with availability for installing these systems in a completely urbanized basin.

We have identified six different areas in the Belém River basin that can install filtering gardens (wetlands) and one outside the watershed. These areas have space available for these systems and are located at strategic points in the basin (Figure 3 and 4):

1. The first viable intervention point is the pond of São Lourenço Park (22 J 674373.82 m E; 7191306.90 m S), in the upper part of the Belém River basin. In this region, there are already significant amounts of sewage. As there is already a retention basin created in the riverbed - the São Lourenço pond was designed to minimize urban flooding in the region - it would be possible to use the lagoon to treat the water.
2. After the Belém River passes over the central part of the city of Curitiba fully channeled, it returns to the surface next to the city bus station (22 J 675005.05 m E; 7185589.25 m S); this is the second stretch of possible intervention for the insertion of wetland systems. This place is important because it is next to the bus station and is a city's business card.
3. After the Belém River passes through the bus station area, it receives water from three of its most polluted tributaries, the Ivo River, the Água Verde River, and the Juvevê River. The third point of intervention is in the same mesoregion of the bus station next to the mouth of the Juvevê River (22 J 675577.20 m E; 7185351.51 m S). This stretch and the previous are strategic for the city due to their central and representative locations. In this stretch, besides the water's foul smell, there are constant floods in periods of intense precipitation, problems that could easily be solved using BGI systems. The region also is in the neighborhood of a peripheral area of the city that needs a rejuvenation project.
4. Despite the Forest Code (Law No. 12,651 of May 25, 2012) requiring riparian forest even in urban rivers, one of the few stretches of the Belém River that actually has riparian vegetation and refuges for biodiversity is where the river crosses the Pontifical Catholic University of Paraná (PUCPR). This area is the fourth stretch with availability for the installation of wetland systems on the riverbed (22 J 675894.17 m E; 7184245.17 m S).
5. The fifth stretch of possible intervention is just before the bridge on Street Rodolfo Bernardelli, in the neighborhood of Uberaba (22 J 677886.99 m E; 7179531.49 m S). This stretch is also impacted by floods when heavy rains occur, and the BGI systems could also contribute to mitigate the floods.
6. The last stretch of intervention with an available area is just before the mouth of the Belém River, in the neighborhood of Boqueirão (22 J 679584.10 m E; 7177424.28 m S). This area is the region of the Náutico of Iguaçu Park. The installation of filtering gardens, further reducing the pollution load that the Iguaçu River receives could be another attraction for the park and also minimize the risk of flooding events that occur in the region.
7. The Urban Drainage Channel is an artificial channel built up to mitigate floods in the region. This channel was constructed in a region that is not yet urbanized between São José dos Pinhais and Curitiba (Figure 4), where other wetland systems can be developed outside the Belém watershed (22 J 679364.99 m E; 7176308.19 m S). Additionally, this alternative can receive the effluents of the Belém Wastewater Treatment Plant for a post-treatment in this wetlands system.

Figure 3 – Possible areas available for the installation of wetlands in the Belém River basin.



Source: Authors, 2021.

The seven proposed intervention points, six within the Belém River basin and one outside the basin, would be multifunctional investments. BGIs have great acceptance by the population (Schröder et al., 2007) and create iconic spaces because the environments that compose them can be used as social and leisure spaces. Still, these works may represent projects of urban rejuvenation for abandoned parts of the city and efforts to renaturalize the city and create spaces for biodiversity. Filtering gardens can be research areas for universities and urban parks with the potential to stimulate environmental awareness for audiences of various ages. These opportunities present at all proposed intervention points.

In addition to the availability of the area, two other challenges for the installation of these systems in urban areas are 1) their implementation costs and 2) political and bureaucratic issues. Intervention area 3 (Figure 3) was recently proposed to create a filter garden, which unfortunately was blocked by bureaucratic and political obstacles. The project proposed for this area had a direct estimated cost (Instituto Água e Terra, 2021) of R$ 2.5 per inhabitant (considering the population of Curitiba) to create an urban park that could significantly improve the quality of the waters of the Belém River, reduce the risk of floods, and promote the urban rejuvenation of the region. Due to the multifunctionality of a project of this type, it is difficult to economically value all the benefits associated with several areas of urban management, such as sanitation and urbanism. However, strategic and alternative interventions like this in important regions of Curitiba have the potential to benefit the entire population of the city with their environmental and social content, which makes them cheap in terms of cost per inhabitant.

Figure 4 – View of the mouth of Belém River.

Source: Authors, 2021.

In Brazil, several wetland experiments can be identified in the literature to treat domestic and industrial effluents. The diversity of plant species that can be used is quite large for multiple purposes. The comprehensive bibliographic review of Machado et al. (2017) pointed out 28 different species of plants, including native, naturalized, and exotic plants, being used in Brazil. The pollutants removal efficiency is naturally related to the plant species used. Some researchers argue that wetlands can remove a broad spectrum of pharmaceuticals (Verlicchi & Zambello, 2014). This is not so with advanced treatment technologies, which in general can remove only certain types of compounds (Kümmerer, 2009). According to Verlicchi & Zambello (2014), this is due to the coexistence of several microenvironments in the wetlands, such as anoxic, aerobic, and anaerobic, and different mechanisms involved in the treatment process, such as biodegradation, sorption, absorption, and also photodegradation.

Based on studies about the use of constructed wetlands to remove pharmaceuticals (Conkle et al., 2008; Breitholtz et al., 2012; Qiang et al., 2013; Li et al., 2014; Verlicchi & Zambello, 2014; Gorito et al., 2017), and the most common species used in wetlands in Brazil (Machado et al., 2017), the most suitable plants for Belém River basin are likely *Typha spp*, which is native to Brazil, and *Phragmites australis*, which is naturalized. Both could be used for effluent treatment and have also been tested internationally to remove pharmaceuticals with good efficiency for a wide range of medical substances.

4. CONCLUSION

Climate change is a new challenge for urban management, which requires the paradigms of preparedness for cities and a resilient and preferably interconnected urban water system. Holistic alternatives such as BGIs can reduce concentrations of polluting pharmaceuticals and make the city more resilient to the effects of climate change. In the Curitiba region, the BGIs with wetlands, due to their multi-benefits, are more feasible than traditional technologies (grey infrastructure) to reduce pharmaceutical residuals pollution in water. It can be used centrally - by the local sanitation company to treat sewerage - and decentralized - by the government in water bodies to treat several kinds of water. In addition to reducing these pollutants, the use of these systems would undoubtedly result in a significant improvement in general water quality. It also provides an opportunity for the sanitation companies to evaluate the possibility of constructed wetlands implementation as a post-treatment of the existing wastewater treatment plants or even as an alternative to expanding the current system. We suggested experiments with pilot systems in the Curitiba region using the species *Typha spp* and

Phragmites australis so that the best operational parameters for the wetlands can be defined and the removal efficiencies of the priority pharmaceutical pollutants for the region evaluated.

Paradoxically, small budgets can act to promote alternative solutions such BGI in urban water management. Proposals and solutions such as BGIs have already been implemented in several countries and, for their cost-benefit, are a promising alternative for the developing world. Indeed, there is a receptivity on the part of the population for these types of projects. Public policies are implemented not only for the quality of what is proposed and for the social interest that they must contain but also because of their public acceptance. BGIs can create iconic features within a city and suggest sustainable characteristics in a mixed urban space, all while solving critical urban problems, such as floods and water pollution. This combination of attributes, the good acceptance of the population, and the low cost in comparing traditional alternatives can enhance public water management policies and motivate projects with this interest.

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