Nature-based Solutions (NbS) for increasing urban greening and reducing runoff flows in narrow streets

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3 authors:

Valéria Borges Yonegura
Universidade Federal do Rio Grande do Sul

Jennifer Domeneghini
Universidade Federal do Rio Grande do Sul

André Luiz Lopes da Silveira
Universidade Federal do Rio Grande do Sul

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Soluções baseadas na Natureza (NbS) para aumentar o ecologismo urbano e reduzir os fluxos de escoamento em ruas estreitas

Soluciones basadas en la naturaleza (NbS) para aumentar la ecologización urbana y reducir los flujos de escorrentía en calles estrechas

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Valéria Borges Yonegura
Master in Geography by Universidade Estadual de Maringá (UEM)
Institution: Universidade Federal do Rio Grande do Sul (UFRGS)
Address: Rua Sarmento Leite, 320, Porto Alegre – RS, CEP: 90050-170
E-mail: projetobyvaleria@gmail.com

Jennifer Domeneghini
Master in Urban and Regional Planning
Institution: Universidade Federal do Rio Grande do Sul (UFRGS)
Address: Rua Sarmento Leite, 320, Porto Alegre – RS, CEP: 90050-170
E-mail: jennidomeneghini@gmail.com

André Luiz Lopes da Silveira
Doctor of Water Sciences in the Continental Environment by Université de Montpellier II - FR
Institution: Universidade Federal do Rio Grande do Sul (UFRGS)
Address: Rua Sarmento Leite, 320, Porto Alegre – RS, CEP: 90050-170
E-mail: andre.iph@ufrgs.com

ABSTRACT

When we explore Nature-based Solutions (NbS) and their implementation in small cities with narrow streets and sidewalks as a feature of their historical cores, we can discover several challenges in terms of sustainability and microclimate regulation. The small cities in the Global South differs significantly from that in the Northern Hemisphere, because their financial reality; it is critical for the community, public authorities, and academia to collaborate to find accessible and novel approaches. Fighting floods and enhancing the environment in these tiny cities can begin with the reintroduction of vegetated spaces and their integration with Blue and Green Infrastructures, thereby assisting grey infrastructures in urban landscape planning. This article is an exercise result of the insertion of NbS in Cachoeira do Sul (RS) - Brazil, city located in the Guarani aquifer zone. The use of NbS was intended to increase drainage area, reduce runoff flows, and provide others ecosystem services in an urban street with nearly no vegetation, or spaces for this. The efficacy of the concept was investigated through the LID-TTT program, allowing to suggest its application in others streets and avenues in the same city. We were also able to use it to model other scenarios in the studied section, seeking an increase in permeability, modifying street coverings and walkways. This surge could also occur by building eco-corridors to enhance connectedness among isolated remnant patches in the city (green areas in backyards, squares, and urban edges), resulting in an increase in biodiversity. This paper intends to propose tiny solutions to dealing with recent flooding caused by current extreme weather conditions.

Keywords: Blue-Green Infrastructure. Ecosystem Services. Green Infrastructure. Landscape Connectivity. Landscape Planning.

RESUMO

Quando exploramos as Soluções baseadas na Natureza (SbN) e a sua implementação em pequenas cidades com ruas e passeios estreitos como característica de seus centros históricos, podemos encontrar vários desafios relacionados à sustentabilidade e regulação do microclima. As pequenas cidades do Sul Global diferem significativamente daquelas do Hemisfério Norte, devido à sua realidade financeira; é fundamental que a comunidade, o poder público e o meio acadêmico colaborem para encontrar abordagens inovadoras e acessíveis. O combate às inundações e a melhoria do ambiente nestas pequenas cidades podem começar com a reintrodução de espaços vegetados e a sua integração com Infraestruturas Verde e Azuis, auxiliando as infraestruturas cinzas no planejamento da paisagem urbana. Este artigo é resultado de um exercício de inserção de NbS em Cachoeira do Sul (RS) - Brasil, cidade localizada na zona do aquífero Guarani. O uso de NbS teve como objetivo aumentar a área de drenagem, reduzir os fluxos de escoamento superficial e fornecer outros serviços ecossistêmicos em uma rua urbana quase sem vegetação, ou espaços para isso. A eficácia do conceito foi investigada através do programa LID-TTT, permitindo sugerir sua aplicação em outras ruas e avenidas da mesma cidade. Também pudemos utilizá-lo para modelar outros cenários no trecho estudado, buscando o aumento da permeabilidade, modificando revestimentos de ruas e calçadas. Este aumento também poderia ocorrer através da construção de corredores ecológicos para melhorar a ligação entre manchas remanescentes isoladas na cidade (áreas verdes em quintais, praças e periferias urbanas), resultando num aumento da biodiversidade. Este artigo pretende propor pequenas soluções para lidar com as recentes inundações causadas pelas atuais condições meteorológicas extremas.

Palavras-chave: Conectividade da Paisagem. Infraestrutura Verde. Infraestrutura Verde e Azul. Planejamento da Paisagem. Serviços Ecossistêmicos.

RESUMEN
Cuando exploramos las soluciones basadas en la naturaleza (NbS) y su implementación en pequeñas ciudades con calles estrechas y aceras como una característica de sus núcleos históricos, podemos descubrir varios desafíos en términos de sostenibilidad y regulación microclimática. Las pequeñas ciudades del Sur Global difieren significativamente de las del Hemisferio Norte, debido a su realidad financiera; es fundamental que la comunidad, las autoridades públicas y el mundo académico colaboren para encontrar enfoques accesibles y novedosos. La lucha contra las inundaciones y la mejora del medio ambiente en estas pequeñas ciudades pueden comenzar con la reintroducción de espacios con vegetación y su integración con la infraestructura azul y verde, ayudando así a la infraestructura gris en la planificación del paisaje urbano. Este artículo es el resultado de un ejercicio de inserción de NbS en Cachoeira do Sul (RS) - Brasil, ciudad ubicada en la zona acuífera guaraní. El uso de NbS estaba destinado a aumentar el área de drenaje, reducir los flujos de escorrentía y proporcionar otros servicios ecosistémicos en una calle urbana sin casi vegetación, o espacios para esto. La eficacia del concepto se investigó a través del programa LID-TTT, permitiendo sugerir su aplicación en otras calles y avenidas de la misma ciudad. También pudimos utilizarlo para modelar otros escenarios en la sección estudiada, buscando un aumento de la permeabilidad, modificando los revestimientos de calles y pasarelas. Este aumento también podría ocurrir mediante la construcción de corredores ecológicos para mejorar la conexión entre los parches remanentes aislados en la ciudad (áreas verdes en patios traseros, plazas y bordes urbanos), lo que resultaría en un aumento de la biodiversidad. Este documento tiene la intención de proponer pequeñas soluciones para hacer frente a las recientes inundaciones causadas por las condiciones climáticas extremas actuales.

Palabras clave: Infraestructura Azul-Verde. Servicios Ecosistémicos. Infraestructura Verde. Conectividad del Paisaje. Planificación del Paisaje.

1 INTRODUCTION

The pressures of increasing urbanization today affect even small cities, and one of the key issues is the loss of permeability. This has a direct impact on the hydrological cycle in cities, emphasizing the importance of proper urban and landscape planning. The appropriate management of urban water drainage systems is vital for controlling and regulating runoff effects (PUGLIESE *et al.*, 2022) especially in a region belonging to the Guaraní aquifer. To solve urban environmental challenges, like these and others, sustainable approaches related to urban rainwater management, such as Best Management Practices (BMPs) and Low Impact Development (LID), are associated with others such as Nature-based Solution (NbS), a concept that according to Pauleit *et al.* (2017) is rooted in climate change mitigation and adaptation.

This paper is the result of a landscape planning exercise that aimed to find and understand existing NbS and propose new ones for implementation in the city. Firstly, by investigating the presence of unplanned NbS in Cachoeira do Sul, RS, Brazil. Thereafter, by analyzing and attempting to fix problems discovered by utilizing NbS to microclimate, well-being and biodiversity enhancing. Subsequently, the evidence of solution efficiency was evaluated using the software LID-TTT application. According to Cohen-Shacham *et al*. (2019), the International Union for Conservation of Nature (Cohen-Shacham 2016) defined NbS as "actions to protect, sustainably manage, and restore natural or modified ecosystems that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits". Some NbS are present in ancient solutions and are often not recognized as a good option; they can be modified or lost, for example, the street pavement composed of cobblestones (one more drainage area for the city).

The main concern discovered in this study is the loss of greenery in a small town once regarded as highly wooded, thanks to urban afforestation done between the 1900s and 1930s. There was no management strategy after that, and many trees were cut down or fallen. There is also an increase in soil sealing; and soils, conforming to Cooper (2020), are important for infiltration, run-off, and stormwater storage. This loss of permeability, which occurs in a city upon the Guaraní aquifer outcrop zone (Machado 2005), is another most serious issue, followed by others such as lack of walking comfort and the formation of heat islands as a result of narrow streets and sidewalks, as well as buildings with no landscaped areas in front of constructions.

The findings of this investigation prompted a proposal to swap specific parking spaces for green spaces, which was initially suggested only along a part of the city's main commercial route. When combined with expanded urban afforestation, this strategy is intended to improve permeable regions, reduce runoff, promote well-being, and eliminate potential heat islands. This approach would benefit local commerce and could be implemented throughout the city, creating ecological corridors and boosting ecosystem services. These corridors could be seen as a network, as a Blue Green Infrastructure[1].

This paper focused on identifying and comprehending current Nature-based Solutions (NbS) at Cachoeira do Sul, Brazil, while also suggesting new ones for integration within the urban environment.

It is structured as follows. Right after this introduction, we will go into some historical characteristics of Cachoeira do Sul urbanization, its biome and our study zone. The subsequent section describes the methodology, processes, and criteria used in this study. The research findings are presented and discussed in the fourth section. Finally, the conclusion section emphasizes the theoretical and practical contributions of the study.

1.1 CACHOEIRA DO SUL AND ITS BIOME

Cachoeira do Sul is a municipality in the state of Rio Grande do Sul, in the south of Brazil with a territorial area of 3,736,064 km2 and population of 80,070 individuals in 2022, resulting in a demographic density of 21.43 inhabitants/km2 (IBGE 2023). In terms of urban dwellings, 89.8% are placed on streets with trees, whereas 25.7% are located on public streets with suitable urbanization (culverts, sidewalks, asphalt, and curbs).

This city is located in Rio Grande do Sul's central depression, at latitude -30º14'09” and longitude -52º58'43”, with an urban zone´s average altitude of 26m (Schuh and Carlos 1991). The climate, pursuant to the classification of Köppen-Geiger (1928), is subtropical (CFa) with a humid climate and hot summer (Pohlmann and Lazzari 2018), but with a softening of the temperature by the waters of the Jacuí River and the cold winter, with temperatures negative in the

[1] Blue Green Infrastructure (BGI) is defined as an interconnected network of natural and man-made landscape components such as open, green spaces and water bodies (ephemeral, inter-mittent, and perennial). BGI, also known as green infrastructure (GI) or nature-based solutions (NBS), is distinguished by the fact that it is expressly built to turn 'blue' (or 'bluer') during rainy events in order to manage stormwater and minimize flood risk. (LIAO, 2019)

higher parts of the municipality (CPTEC). The average annual temperature is 19.1°C; with an average of 24.2ºC(±1.4º) in February; and the 13.4ºC (±1.5ºC) in July (Pohlmann and Lazzari 2018).

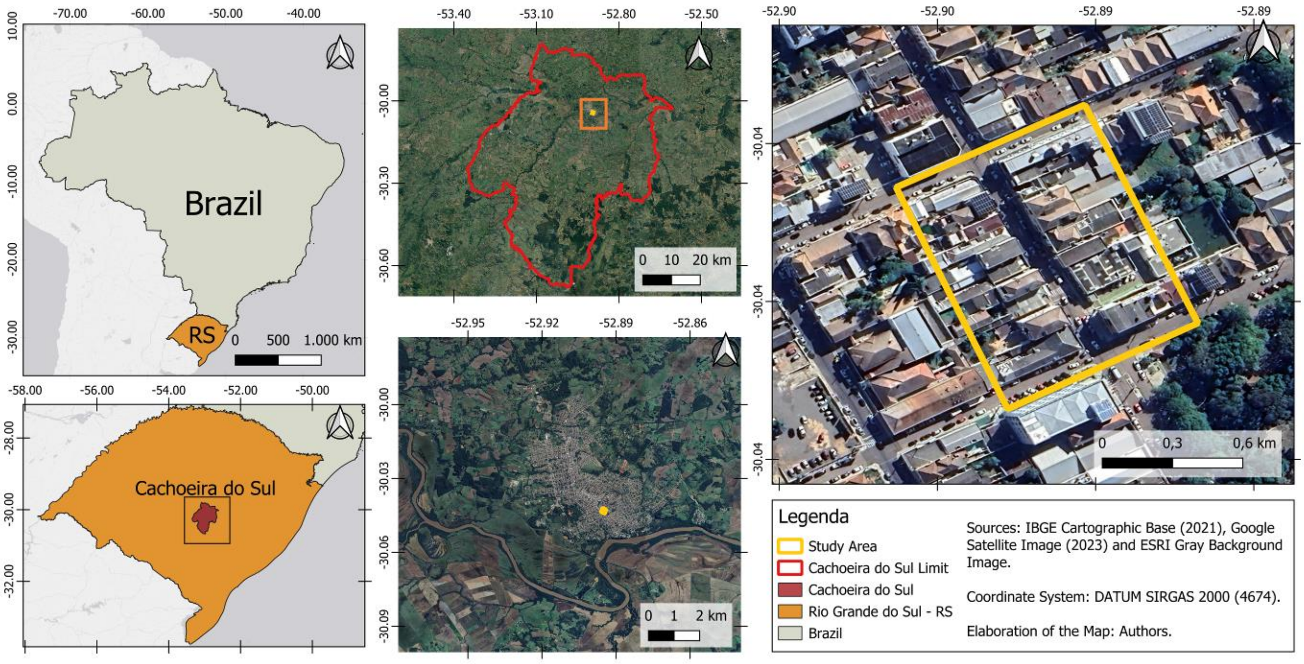
The average rainfall in this climate is 1,477 mm/year, with August being the wettest month, with 157.4 mm, and April the driest, with 83.6 mm (INMET). The city experiences a water deficit of 85 mm between December and March, with periods of drought during the summer not being rare (INMET).

Cachoeira do Sul is at physiographic region of the Central Depression of Rio Grande do Sul State, beside the Jacuí River. The soil is a Planossolo Háplico Eutrófico Arênico at Brazilian soil classification (Vedelago 2014). According to Solos (2018, p.259), is a soil with a sandy texture from the surface to a minimum depth of 50 cm and a maximum depth of 100 cm.

1.2 STUDY ZONE

The study area is located in the central region of the municipality (Fig. 1) and a section of 7 de Setembro Street was chosen because it is an important commercial street with considerable traffic, with its narrow sidewalks and entirely occupied lots, without urban trees (Fig. 2). This street connects two relatively close green patches, José Bonifácio Square, where the street is wider, and further ahead, Honorato de Souza Santos Square.

Figure 1. Map of Location of the Study Area. Google photo showing the connection of the study area to a square.



Source: Authors, 2023

This 203-year-old city's greenering is vanishing (Fig.2). We only have green spaces in the city center on old squares and on certain traditional residential lands, and with verticalization, these massive trees and houses are dropped below to be replaced by little buildings with extremely limited setback grounds and no gardens. Meanwhile, asphalt is replacing permeable pavement streets, increasing waterproofing and the speed of rainwater runoff in a city with an old and undersized drainage system. The fundamental difficulty in this city is the loss of green and pervious locations; the streets are mostly small, and there is barely any space for trees on the sidewalks. The first seedlings for urban afforestation were requested in 1906, coming from the state capital at a period when the city was being urbanized (Schuh and Carlos 1991, p.134).

Figure 2. Afforestation in 7 de Setembro Street beside José Bonifácio Square, Cachoeira do Sul, undated (Studio Aurora); narrow streets (cobblestones pavement) and sidewalks, no room for trees and marquises can limit its development

Source: Authors 2023

The paving of city roadways in cobblestones (Fig.2 and Fig.3) built during urbanization could be viewed as a NbS, assisting in rainwater drainage, an ecosystem service[2]; or to others authors, a landscape service[3]. NbS terminology first appeared around 2002 (Cohen-Shacham *et al*. 2016), it is also known as Green infrastructure (GI) or Blue Green Infrastructure (BGI) (Cooper 2020); however, the use of natural processes to manage water likely dates back millennia (WWAP/UN-Water 2018). In accordance with Benedict and McMahon (2006), the term GI differs from conventional approaches to land conservation and natural resource protection because it considers conservation in conjunction with land development and man-made infrastructure planning. Escobedo *et al*. (2019, p.10) state that "GI pays more attention to the spatial pattern and connectivity of the natural network", while the term BGI refers to a structure that

[2] Christensen *et al*. (1996) define ecosystem services as a variety of commodities and services given by ecosystems, on which people rely directly or indirectly. In compliance with Millennium Ecosystem Assessment (Reid *et al.* 2005), "Ecosystem services are the benefits people obtain from ecosystems", they can be divided in four categories: " *provisioning services* such as food, water, timber, and fiber; *regulating services* that affect climate, floods, disease, wastes, and water quality; *cultural services* that provide recreational, aesthetic, and spiritual benefits; and *supporting services* such as soil formation, photosynthesis, and nutrient cycling.". For Pauleit *et al.* (2017), the benefits that humans obtain from urban nature are valued by ESS.

[3] According to your usage, authors such as Lamarque *et al*. (2011) propose a distinction of terminology from these "benefits that people receive from biodiversity and ecosystems.". *Ecosystem services* are used in the context of biodiversity protection and natural ecosystems, while *Landscape services* are used in land-use planning because they are based on land-use patterns and practices and are amenable to human interventions.

is specifically designed to turn 'blue' (or 'bluer') during rainy events in order to manage stormwater and reduce flood risk (Liao 2019).

The cobblestone paving, saw in this exercise as a NbS, is gradually being filled by asphalt, which benefits cars (no more shaking due to flaws, covering a historic mark that might be seen as a delay). At the same time, afforestation in the first part of the twentieth century was heavily reduced or destroyed due to senescence, pest problems (such as termites, xylophagous insects of the order Isoptera), or the owner's desire. The few trees we come across on our walks are mainly in small rooms and are nonetheless subjected to severe pruning. These rooms, as seen in Fig.4, are not beneficial for the trees and are insufficient for drainage, especially on asphalted streets. The remaining green areas (Fig.3 and Fig.4) are fruit trees and huge trees in the middle of blocks, in backyards, or leafy trees in squares and educational institutions.

Figure 3. Substitution of green backyards, reminiscent afforestation outside city core, cobblestones pavement and extreme pruning tree in an asphalted street.

Source: Authors, 2023

Figure 4. Blocks almost completely occupied. Remaining trees from urban afforestation and some old and green backyards.

Source: Google Earth, 2023

With the increased value of urban land, many of these homes, which were once on large lots, are being demolished to make way for residential constructions. Citizens' acceptance of the new and “modern” implies that they do not question the maximal use and the soil sealing effects. According Tucci (2005), excessive waterproofing in urban areas results in significant drainage problems and, consequently, flooding, a current reality in the city.

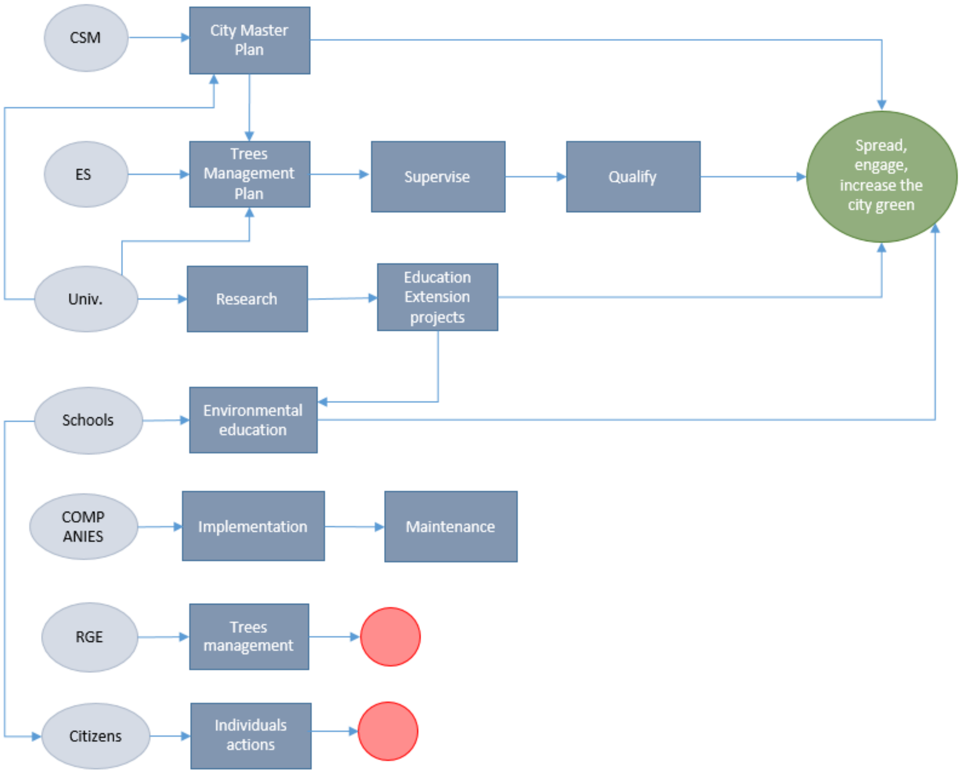
2 METHODS

2.1 AGENTS AND A NEW PROPOSAL

We believe that environmental education plays an important role in raising public awareness. Ordinary citizens can rise above their apathy and complaints about excessive temperatures, torrential rains, or droughts, and become a participating and supervising agent (in the sense of preservation).

At the time, some agents are treating environmental subjects, as shown in Fig. 5:

Figure 5. Agents and currency policy framework.



Source: Authors, 2023

Cachoeira do Sul Municipality (CSM) – administers the city and is now reviewing the city's master plan with the local universities and the community;

Environmental Secretary (ES) – among the various secretariat tasks, include: environmental inspection, fauna and flora preservation, parks and squares implementation, maintenance and environmental education promotion;

RGE – city energy supplier in charge of urban tree pruning near overhead power wires;

Companies, local associations and banks – companies, local organizations, and banks could use public green spaces such as central flowerbeds and squares to install and maintain gardens. In addition to the participation of the local Rotary Club, certain businesses in the city already do this;

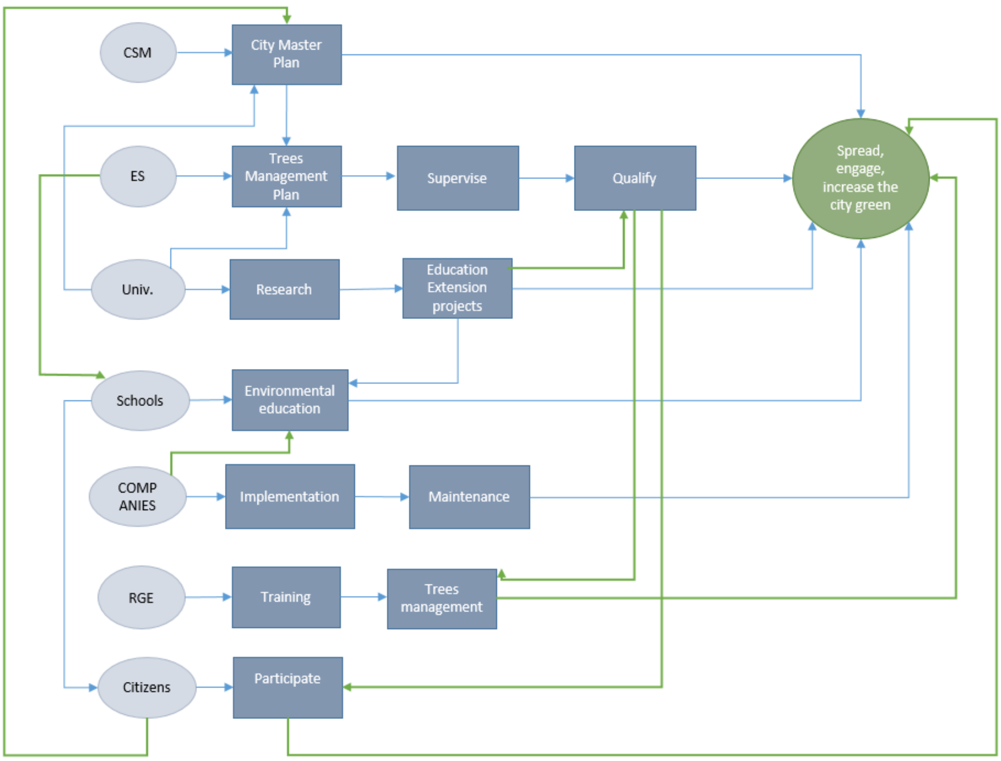
Schools and universities – environmental education and campaigns in schools, university extension initiatives involving research and development of afforestation projects and other nature-based solutions;

Citizens of Cachoeira do Sul – they require education to grasp the value of a less impervious and greener environment, as well as its benefits and increased quality of life.

With a few changes and the cooperation of the agents, we may achieve a more efficient rearrangement (Fig.6). This would occur if the following adjustments were made:

- Increased public participation in the review of the master plan;
- Greater involvement of local universities in education extension programs, training for public agents (to reach schools, public authorities, and citizens), and RGE, for better pruning training;
- Companies that promote environmental education in schools through profits and campaigns in partnership with the environment secretary;
- A law requiring appropriate permeable space in new projects, as well as tax breaks for NbS such as green roofs, green walls, draining floors, and rain gardens (among others).

Figure 6. Proposed framework.



Source: Authors, 2023

The goal of this new framework is to improve agent quality and training, engage citizens, build more effective campaigns, and qualify the participants. Their participation is essential for the acceptance and maintenance of the proposal developed in the exercise.

2.2 METHODOLOGY FOR THE APPLICATION OF LID TTT

The Low Impact Development Treatment Train Tool (LID TTT) approach was collaboratively developed by the Lake Simcoe Region Conservation Authority (LSRCA), Credit Valley Conservation (CVC), and Toronto and Region Conservation Authority (TRCA) with the primary objective of promoting and implementing more sustainable planning and management practices for rainwater. This innovative tool is designed based on the Storm Water Management Model (SWMM5).

The LID TTT 2.2.9 software serves the purpose of analyzing both annual runoff volumes and event-based runoff, while also quantifying the removal of polluting loads through the utilization of Low Impact Development (LID)[4] and Best Management Practices (BMPs)[5] techniques. Its application aims to enhance the effectiveness of stormwater management and contribute to the preservation of water quality in various urban and natural environments (Chang *et al*. 2018; Abdeljaber *et al*. 2022).

For the analysis, four scenarios were created in the software. The pre-development scenario encompasses the area in its current state. Meanwhile, in the post-development scenario, Low Impact Development (LID) techniques are applied to the area to meet the final objective, following the LID TTT manual

[4] In a terminology study of urban drainage approaches, Fletcher *et al.*(2015) cite the term lid as originally focused on using site design to minimize impermeable areas and retain natural areas. It is characterized by smaller scale stormwater treatment devices, such as bio-retention systems, green roofs and ditches, located at or near the source of runoff.
[5] According Fletcher *et al.*(2015), BMP means a form of practice or structured approach to pollution prevention. BMPs for stormwater management would comprise a technique, process, activity, or structure to reduce the pollutant content of stormwater discharge, and might be implemented singly or in tandem to maximize effectiveness. BMPs achieve this by combining non-structural measures (such as good housekeeping and preventive maintenance) with structural deployments (such as bioretention systems or green infrastructure).

guidelines (STEP, 2018). Thus, three post-development scenarios were created: first, with green spaces and cobblestones, without a draining pavement on the sidewalk; second, with green spaces and asphalt, without a draining pavement on the sidewalk; and finally, green spaces, asphalt, and a draining pavement on the sidewalk. The flow coefficients for the paving materials utilized were determined by research conducted by the US Green Building Council (2023) and Araújo *et al*. (1999), and they are as follows: asphalt (0.95), cobblestone (0.60), concrete sidewalk (0.95), and porous concrete sidewalk (0.005). Criteria for the characteristics of the rain and the goal of controlling stormwater runoff were adopted for the definition of the scenarios based on IMNET data and the study by Marostica *et al*. (2023), as the city considered has similar characteristics to the city studied. The necessary and adopted criteria for scenario development were as follows:

- Storm type and distribution: The storm distribution was based on SCS (Storm Distribution Select) criteria;
- Total rainfall depth: 27 mm;
- Rain duration in hours: 4 hours without interruption;
- Control of stormwater runoff volume: The target was to reduce the depth of rainfall by 25mm.

Finally, after the creation of the two designed scenarios, the program generated reports to analyze the devices that implement LID techniques, as well as the benefits and drawbacks in the potential control of rainwater for the specific case study.

3 RESULTS AND DISCUSSION

3.1 MORE NATURAL ELEMENTS: PARKS SPOTS CONVERTED IN GREEN SPACES

As a solution that can increase the biomass and draining area of the site chosen for the study, while supplying provisioning, supportive, regulating and cultural ecosystem services, some parking areas would be converted into green spaces. We may expand green areas, increase urban rainwater collection, raise thermal and visual comfort for better walkability, and improve space with small rain gardens (or bioretentions points). The area can be made more beautiful, become an attraction for commerce, provide a spot for pedestrians to rest or socialize, and give space for trees of different sizes.

This NbS proposed is aligned with ODS11 - Make cities and human settlements inclusive, safe, resilient, and sustainable – promoting inclusive and sustainable urbanization, reducing the environmental impact of cities and decreasing water-related troubles. Where water is polluted, both constructed and natural ecosystems can help improve water quality by lowering sediment loadings, absorbing and holding contaminants, and recycling nutrients (WWAP/UN-Water 2018).

Though limited information is currently available and long-term field-based in-situ studies on bioretention systems performance are required, this NbS shows promising performance for managing stormwater hydrology (attenuation of runoff volume and peak flows) and the removal of stormwater pollutants (TSS, TN, TP, heavy metals, etc.) through microorganisms (i.e., bioremediation) and planted vegetation (i.e., phytoremediation), conforming to Biswal *et al.* (2022). In the opinion of these authors, the key methods for removing pollutants from runoff in NbS include physicochemical processes such as filtration, adsorption, precipitation, and complexation, as well as biological activities such as plant absorption, microbial assimilation, and biological elimination routes.

For Benedict and McMahon (2002), the strategic placement of green infrastructures reduces the need for gray infrastructure, freeing public funds for other community needs. Furthermore, in this exercise, it could provide the following ecosystem services:

- Provisioning services: flowers, organic substrate development materials (tree leaves, small branches, and flowers);
- Supportive services: increased biodiversity, food and shelter for avifauna (birdlife), photosynthesis and reduction of air pollution;
- Regulating services: climate control and improved walkability, water regu-lation and purification (helping with stormwater pollutants like Total

Suspended Solids (TSS) retention, and Total Phosphorus (TP) before urban water replenishes the aquifer), air purification, carbon sequestration and storage, pollinator attraction and shelter, and an increase in the drainage surface of urban waters;

- Cultural services: the streets would be more attractive and healthier, attracting more people to use the space; it would also serve as an additional source of trade and a place to sit or have chimarrão (mate herb) with friends (social cohesion).

3.2 TREES FOR THE GREEN SPOTS AND STREET AFFORESTATION

In this scenario, the sidewalk width is too narrow and varied for an urban afforestation with large or medium-sized trees. In this study, certain trees with bigger diameters would be planted in green spots (transformed park locations into green spaces), while the diameters of the others would vary depending on the available area. Six green spots would be generated for afforestation in this 101-linear-meter-long block (Fig. 7). Due to the electrical wiring, three 6m diameter trees would be planted on one side and three 5m diameter trees on the other. Trees with a maximum diameter of 3m would be planted in the 2m wide sidewalk, and 4m diameter trees would be planted on the other sidewalk, which varies in width from 3m to 3.3m; in short, 12 trees on each side, plus 6 on the green spaces.

Figure 7. Pilot block and possible expansion. Green spots locations (D) and schemes for green spot and pervious sidewalks.

street section (the pilot block)
streets where the same solution could be applied

A – Part of city core
B – Pilot block

C – Sidewalk and Green spot section
D – Green spots and street afforestation
E – Green spots and afforestation sketched

Source: Authors, 2023

Table 1. Permeable areas for the afforestation, green spots proposed and others possible scenarios

Description	Qty.	Pervious area
5m diameter trees (room with 1x1m in green spot)	3	3m2
6m diameter trees (room with 1x1m in green spot)	3	3m2
3m diameter trees (room with .60x.60m in sidewalk)	12	4.32m2
4m diameter trees (.70x.70m per room in sidewalk)	12	5.88m2
Green spots (11m2 per parking lot)	6	66m2
Cobblestones street		Nearly 942m2
Asphalted street with pervious sidewalks		Nearly 500m2

Source: Authors, 2023

As seen in Table 1, green spots occupying 6 parking spaces would improve the permeable area in this stretch of street by 66 m2 (2.5 x 5 m space per green spot). The tree species would be deciduous, meaning they would have no leaves in the winter. The rubble removed for its aperture might be used as drainage material beneath a layer of topsoil where herbaceous would grow. The use of this draining aggregate would allow for a deeper space to retain a greater amount of rainwater. Some benches and small spaces for pedestrian use could be placed in these areas. Pervious areas with the use of drainage flooring on sidewalks, we could increase permeable area. We have a permeable street (101m long on this block, 942m2 with cobblestones) that will soon be resurfaced with asphalt. By replacing the sidewalks' pavement floors with permeable floors, we would have more than 499 m2 of permeable flooring in this block.

This green spot could be seen as a NbS for water, as such, it may entail employing or replicating natural processes, protecting or restoring natural ecosystems, and/or augmenting or producing natural processes in modified or artificial ecosystems (Cooper 2020; WWAP/UN-WATER 2018). These areas could work like little vegetated swales or rain gardens, operating during the passage of a storm event with flow attenuation, detention and particle sedimentation, and filtration (Wong *et al*. 2006). According Biswal *et al.*(2022), planting tall, thick, and dense native and non-invasive vegetation species along urban streets demonstrates a favorable impact on reducing air and water pollution in urban environments.

3.3 THINKING ABOUT THE IMPLEMENTATION – EARNINGS, IMPACT AND NEEDS

The trees in this block would form a green infrastructure on one of the city's main commercial streets. At this point, garden roofs are not an option; with sloping clay roofs or fiber cement tiles, the buildings are old and a substantial portion is used for living on the upper floor. As the urban drainage system is ancient and undersized, the locations where the trees would be planted could help drain urban water. The creation of these “new urban drains”, or water retention spaces, would reduce the runoff and delay the arrival of this rainwater in the galleries while retaining part of the urban pollution that would contaminate the waters of the Jacuí River.

Our chosen NbS, green spaces with urban afforestation, can assist in increasing awareness of the need to limit car use, as parking spaces can help in biodiversity and generate aesthetic and psychological well-being in cities. These locations may attract people, which will increase local business in addition to providing ecosystem services. The city hall and the city's trade association may be in charge of implementing these changes, while businesses and banks could adopt spaces for their own maintenance.

We might consider the impact of this new afforestation and transforming parking lots into green spaces in the street zone. Construction, green spot performance, maintenance, and conservation of this site might all take place in three stages:

Construction - during the work to open green spaces and convert the pavement floor to a permeable pavement, there will be reduced pedestrian circulation and an impediment to parking on the streets (at least on one side). Greater dissemination of these changes through city marketing, campaigns, and dissemination in local media will be required, highlighting the benefits of the transformation, particularly with the introduction of green areas. This can mitigate the negative impact of decreased mobility and visibility of local businesses.

Green spot performance - at this point, the intake of urban waters has increased, runoff has decreased, and aesthetics and walking comfort start to improve. Birds and pollinators will be able to find shelter among the trees and flowers. The expense of preserving the space is decreased as a result of the involvement of society and commerce in the surrounding neighborhood, allowing the municipal authorities to prune and maintain the floors, among other more technical security services. Installation of free Wi-Fi hotspots can become the space more attractive. The rent from paid rotational parking can be utilized to sustain or expand the project.

Management and conservation - in addition to the collecting of rainfall by sidewalks and green spaces, there is a delay by the treetops at this point, which may have greatly decreased heat island problems. People will be able to find shade in the summer, and municipal authorities will be able to use their leaves and small branches to make compost substrates. The benefits of these renovations will outweigh the costs; aesthetic appeal, psychological well-being, and an improved microclimate can make the street more appealing and a location to remain longer, promoting trade and tourism. On Sundays, the street could be closed for leisure, municipal festivities, craft fairs, and other events. The benefits obtained can also be used for city marketing.

3.4 A BLUE-GREEN NETWORK

In this urban patch, smaller patches of green areas can be found in old squares, inner blocks and school yards. There are corridors (mostly fragmented) formed by trees on the banks of the "sangas" (small watercourses that run through the city) and in the riparian forest of the Jacuí River, which is a large and important echogenic corridor (Fig. 8). Remains of urban afforestation from the 1920s and 1930s can still be seen on a few streets. Some huge canopies of *Tip-uana tipu* and *Platanus acerifolia* are eye-catching. Two main and three minor perpendicular corridors are designed in the proposal, a Blue-Green Infrastructure (BGI), called in this exercise "green-blue network"; formed by the axes A and B, axis A runs in the same direction as axis B.

Figure 8. Blue-green network: A and B corridors.

Source: Authors, 2023

A – On this street, some parking spaces would be replaced by green spots, allowing for the planting of larger trees to complement the urban afforesta-tion that will be undertaken on the sidewalks. The street is narrow, pre-venting the establishment of a bike lane; however, a green corridor formed by trees would connect two key patches, the city's two main squares, which are both well wooded. In this green-blue network, the drainage of urban rainwater and its gray infrastructure would be aided by the draining pavements of the sidewalks and by the green spaces.

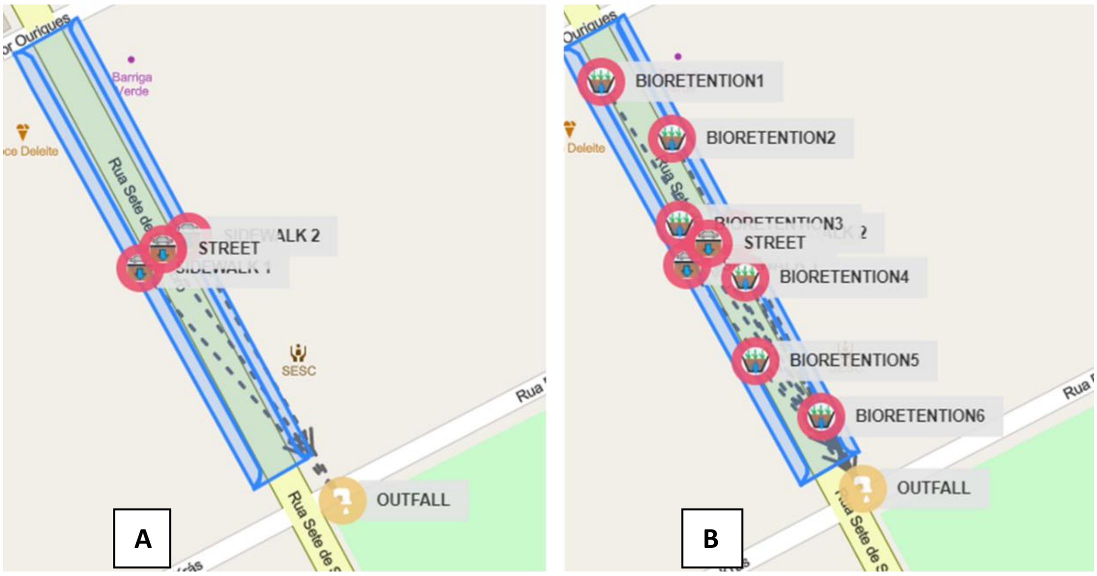
B- It is the city's longest corridor, linking the river to the other city side. The paving stones street were replaced by asphalt on this axis. Because it is a wider street, a bike lane can be built, urban afforestation with bigger trees can be implemented, and the pavement surface of sidewalks can be changed to allow for drainage. Three smaller, perpendicular axes would connect some parts of the city to these two axes, while others small existing patches would act as stepping stones, increasing connectedness between patches and other green and blue corridors.

This BGI was conceived as an interconnected network, connecting green areas that preserve natural ecosystem values and functions while delivering associated benefits to human populations, as proposed by Benedict and McMahon (2002, p.12) in one of the GI's concepts. In addition, this new urban green infrastructure might control hydrological routes, regulate run-off, and recharge groundwater (WWAP/UN-Water 2018; Cooper 2020).

3.5 IMPLEMENTING AND ANALYZING THE GREEN SPOTS WITH LID TTT

In Fig. 9, the conformation of the study areas made through the LID TTT software can be seen based on the current (Fig. 9 – A) and proposed (Fig. 9 – B) scenarios. In the current scenario, there is a division into a street, two sidewalks and the outfall located on the corner (manhole). In the proposed scenarios, there is the presence of the street (not counting the areas of green spaces), six green spaces (bioretentions), two sidewalks, and the same outfall. Only the values of the flow coefficients of the paving materials in these scenarios were modified; the areas stayed the same for scenario comparison purposes.

Figure 8. Division of the areas of the current (A) and proposed (B) scenarios in the LID TTT software.



Source: Authors, 2023

When comparing the present and proposed scenarios in Table 2, with the same area (0.41 ha) and total rainfall of 109.59m3 in 4 hours, several numbers differ. The current scenario has a total infiltration of 32.4 m3 due to the presence of cobblestones and a concrete sidewalk, whereas the other scenarios (2, 3, and 4) have a site infiltration increase of 32.51 m3 due to the implementation of the green spots, that is, bioretentions, or rain gardens, in areas that used to be parking, thus contributing to the increase in infiltration. The volume of external outflow remains the same (30m3) in the current scenario and scenario 2, as there is no change in the floors used in the scenarios. In scenario 3, when cobblestones are replaced with asphalt on the street, this index worsens (33 m3) due to the use of asphalt, a material that does not allow infiltration, as opposed to cobblestones, which have a greater runoff coefficient (0. 6). In scenario 4, even with asphalt, the external flow (8 m3) is reduced due to the use of porous concrete on the sidewalk, which has an excellent flow rate (0.005) compared to the current concrete (0.95).

Because of the materials used in the pavements, the rainfall reduction in the current scenario and scenario 2 remains the same (72.63%), as indicated in the external outflow. In scenario 3, as with the external outflow, it worsens in this regard (69.89%) due to the previously indicated replacement of street material.

In scenario 4, the best scenario, there is an increase of 92.07% in rainwater reduction, resulting in a difference of 20.07% for scenario 1 (the existing one), which is mostly due to the presence of porous pavement.

Table 2. Water Balance Comparison of the Current (1) and Proposed Scenarios (2,3 e 4)

Scenarios	**Site Area**	**Site Rainfall (mm) (m3)**	**Site Infiltration (mm) (m3)**	**External Outflow (mm) (m3)**	**Rainfall Reduction (mm) (%)**
Scenario 1- current scenario, cobbled street and sidewalks without draining floor	0,41 ha	27,06 mm 109,59 m3	8 mm 32,4 m3	7,41 mm 30 m3	19,65 mm 72,63 %
Scenario 2 – green spaces and cobblestones, without draining pavement on the sidewalk			8,03 mm 32,51 m3	7,41 mm 30 m3	19,65 mm 72,63 %
Scenario 3 – green spots and asphalt, without draining pavement on the sidewalk			8,03 mm 32,51 m3	8,15 mm 33 m3	18,91 mm 69,89 %
Scenario 4 – green spots, asphalt and draining pavement on the sidewalk			8,03 mm 32,51 m3	1,98 mm 8 m3	25,08 mm 92,07 %

Source: Authors, 2023

Briefly, the findings demonstrate that LID addresses aid in urban drainage (Marostica *et al*. 2023). As noted above, the addition of small-scale bioretentions contributes little to the proposed scenarios, and the substitution of cobblestones for asphalt revealed that the latter complicates the drainage problem because it is a non-porous material that does not allow infiltration, resulting in floods if it rains significantly in the area. Replacing non-porous concrete with porous concrete was the most effective LID solution for the scenarios, demonstrating how a simple solution of changing the pavement material can help or not in reducing the amount of water that goes to the outflow and thus being able to prevent flooding in the analyzed city.

4 CONCLUSIONS

In a period of extreme weather events, we see this study as a tool to raise awareness and provoke both the community and academia to address an urgent local issue. We saw possibilities for NbS applications in this city after completing this exercise. By adjusting agent functions involved in the execution of NbS, replacing streets and sidewalks coverings, and developing green spaces, we can support improvements in urban space and citizen quality of life. Another issue that must be addressed promptly is the improvement of urban afforestation with deciduous species (due to high summer and low winter temperatures) in adequate rooms. According to various researches, urban afforestation improves microclimate, drainage, and rainwater delay, but these data were not included in this study.

With the analysis of scenarios, we can see that cobblestones are responsible for reducing runoff by 72.63% in the current scenario (1), and with the addition of green spots in scenario 2, little has changed in drainage, but we need to consider its effect on the urban landscape due to the insertion of larger trees as well as the well-being of passers-by. Between scenarios 3 and 4, we can see how changing the pavement would have a significant impact, even if the cobblestones were covered with asphalt in the near future.

The true execution of these interventions would be possible counting on the community's participation, understanding, and patience in the implementation, which would be a crucial issue here. This could be done via campaigns that highlight the project's importance and benefits, with stakeholder and trade association involvement and 'guardianship' of these places. As a result, a new and welcome space for transit would emerge, complete with resting areas, stimulating trade while also providing other ecosystem services such as habitat for wildlife and pollinators. The project's extension can begin with the axes proposed in the study (axis A and B), which take the shape of key echogenic corridors that cross the city from the Jacuí River to the other city end. There are additional smaller axes that connect riparian forest patches in streams, woodland squares, and native forest remnants.

The impossibility of building an on-site model was a limiting factor for this study, even so, the future research could include the development of rainwater containment areas combined with the axes and leisure facilities of the squares indicated in this study. The aesthetic benefit and use of the city's “new identity” by city marketing would increase the value of the region's urban land, boosting the application of these NbS in other sections of the city and could also become a new object of study about this space.

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