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Environment

Economic analysis for implementing sustainable urban drainage systems in amazonian cities: the case of Itaituba, Pará, Brazil

Análise econômica para a implantação de sistemas sustentáveis de drenagem urbana em cidades amazônicas: o caso de Itaituba, Pará, Brasil

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ABSTRACT

Unbridled urbanization causes complex problems for urban drainage during rainy seasons, such as flooding, waterlogging and landslides. The use of Sustainable Urban Drainage Systems (SUDS), combined with conventional networks, presents a promising alternative to reduce such problems in developing cities during the Amazon winter. In this regard, this study analyzed the economic feasibility of using SUDS in the municipality of Itaituba, located in the countryside of the Amazon. To this end, two stages were conducted: SUDS dimensioning, considering rain gardens and infiltration trenches; and estimation of costs for implementing these systems, based on prices from the Brazilian National System of Research of Costs and Indexes of Civil Construction (SINAPI - *Sistema Nacional de Pesquisa de Custos e* Índices *da Construção Civil*) and local quotations. The results indicated that infiltration trenches are, on average, 13% more economical than rain gardens. When only the costs by local quotation are assessed, this savings can reach 27%. In short, it is believed that the results can guide decisions and actions in local urban planning, aiming for a more resilient, sustainable city that is prepared for the challenges related to urban drainage.

Keywords: Urban water; Compensatory techniques; Rain garden; Infiltration trench; Costs

RESUMO

A urbanização desenfreada acarreta problemas complexos para a drenagem urbana nos períodos chuvosos, como inundações, alagamentos e deslizamentos. Para cidades em desenvolvimento na região Norte do Brasil, o uso de Sistemas Sustentáveis de Drenagem Urbana (SUDS), aliado à rede convencional, se apresenta como uma alternativa promissora para reduzir tais problemas durante o inverno amazônico. Nesse sentido, este estudo analisou a viabilidade econômica para o uso de SUDS no município de Itaituba, situado no interior da Amazônia. Para isto, foram conduzidas duas etapas: dimensionamento de SUDS, considerando os jardins de chuva e trincheiras de infiltração; e estimativa de custos para implantação desses sistemas, com base nos preços do Sistema Nacional de Pesquisa de Custos e Índices da Construção Civil (SINAPI) e de cotação local. Os resultados indicaram que as trincheiras de infiltração são, em média, 13% mais econômicas que os jardins de chuva. Quando avaliados, apenas, os custos por cotação local, essa economia pode chegar a 27%. Em suma, acredita-se que os resultados possam orientar decisões e ações no planejamento urbano local, visando uma cidade mais resiliente, sustentável e preparada para os desafios relacionados à drenagem urbana.

Palavras-chave: Águas urbanas; Técnicas compensatórias; Jardim de chuva; Trincheira de infiltração; Custos

1 INTRODUCTION

According to Tucci (2014), urbanization alters the natural hydrological regime, increasing soil sealing, the speed of surface runoff and the generation of peak flows. This scenario is compounded by conventional urban drainage systems, which were based on the hygienist model, whose objective is to conduct rainwater to receive bodies as quickly as possible. In the meantime, these systems face a series of limitations, especially regarding service dimensioning and coverage, considering the advance of urbanization. These factors, combined with a scenario of climate change, contribute to the insufficiency or widespread failure of existing networks, causing frequent flooding and/or inundation in urban centers.

From this perspective, it is necessary to look for new alternatives to the traditional drainage system that allow urban growth combined with sustainable development, in order to reduce the urban impact through easier management access to such innovations (Kniess et al., 2019). According to Silva and Moura (2017), the concept of sustainability has been included in Brazilian scientific debates on urban drainage since the 1990s. With this proposal, there are compensatory, environmental techniques or unconventional systems for urban drainage, which make it possible to obtain the natural processes of infiltration and evaporation, thus aiming to reduce peak flows so that runoff occurs more gradually (Noleto &

Rodrigues, 2024; Alencar et al., 2022). These techniques are part of the concept of Low Impact Development (LID), Best Management Practices (BMPs) and Sustainable Urban Drainage Systems (SUDS).

SUDS technologies, which have been gaining visibility in recent decades, are alternative measures that complement conventional drainage infrastructure, aiming to minimize the hydrological impacts of urbanization and increase the resilience of municipalities to extreme rainfall events (Wang et al., 2017; Zhu et al., 2019). These techniques include rain gardens, which not only reduce flooding, but also mitigate the microclimate and, consequently, improve thermal comfort, contributing to landscaping and quality of life (Melo et al., 2014; Barros et al., 2024), and infiltration trenches, which promote hydrological and environmental benefits, stand out, such as relieving the drainage system, reducing the costs of conventional drainage systems, recharging the water table and improving the quality of rainwater (Melo et al., 2014; Feitosa et al., 2020).

Rain gardens, also known as bioretention beds, are bioretention devices (green infrastructure) installed on the lower levels of land, directing runoff to a system that generally consists of mulch, prepared soil for planting (substrate), coarse sand, gravel and drains. They are ideal for residential areas, as they are dimensioned to receive the volumes of water coming from roofs and sidewalks, helping to reduce flooding on public roads and improve the water quality of water sources (Hunt et al., 2010; Melo et al., 2016; Gondim et al., 2023).

Infiltration trenches are ditches filled with permeable material, such as gravel, which allow rainwater to infiltrate into the ground. They are especially useful in urban areas with compacted soil, where the natural infiltration of water is hindered (Melo et al., 2016; Queiroz et al., 2023).

According to Fogatti, Millan and Martins (2023), replacing conventional drainage infrastructure with this alternative, although positive from a sustainable point of view, economically, installation or maintenance costs may be higher. However, depending on the project to be carried out, Mukhtarov et al. (2019) pointed out that the use of SUDS can be economically viable for techniques such as grassed strips, rain gardens and detention/retention basins.

For developing cities in northern Brazil, the use of SUDS technologies, combined with conventional drainage infrastructure, is a promising alternative for reducing impacts during the Amazonian winter, as they promote rainwater infiltration, contribute to landscaping, reduce pollution and improve the population's quality of life (Mendes & Andrade, 2021). From an economic point of view, on the other hand, implementing SUDS in cities in the countryside of the Amazon can be costly, given the price of inflows in these locations.

Itaituba, located in the state of Pará in the countryside of the Amazon, is an example of city with serious urban drainage problems due to irregular and disorderly occupation, resulting in impacts on local infrastructure and the environment. The city, which is currently undergoing urban expansion, has experienced successive episodes of flooding during the Amazon winter at strategic points of urban mobility, such as the Trans-Amazonian Highway (Silva Junior et al., 2023).

Given this context, this study aimed to analyze the economic viability of implementing SUDS technologies in Itaituba-PA, which are compatible with the climatic and geological conditions of the Amazon region. The rain garden and infiltration trench techniques were thus chosen.

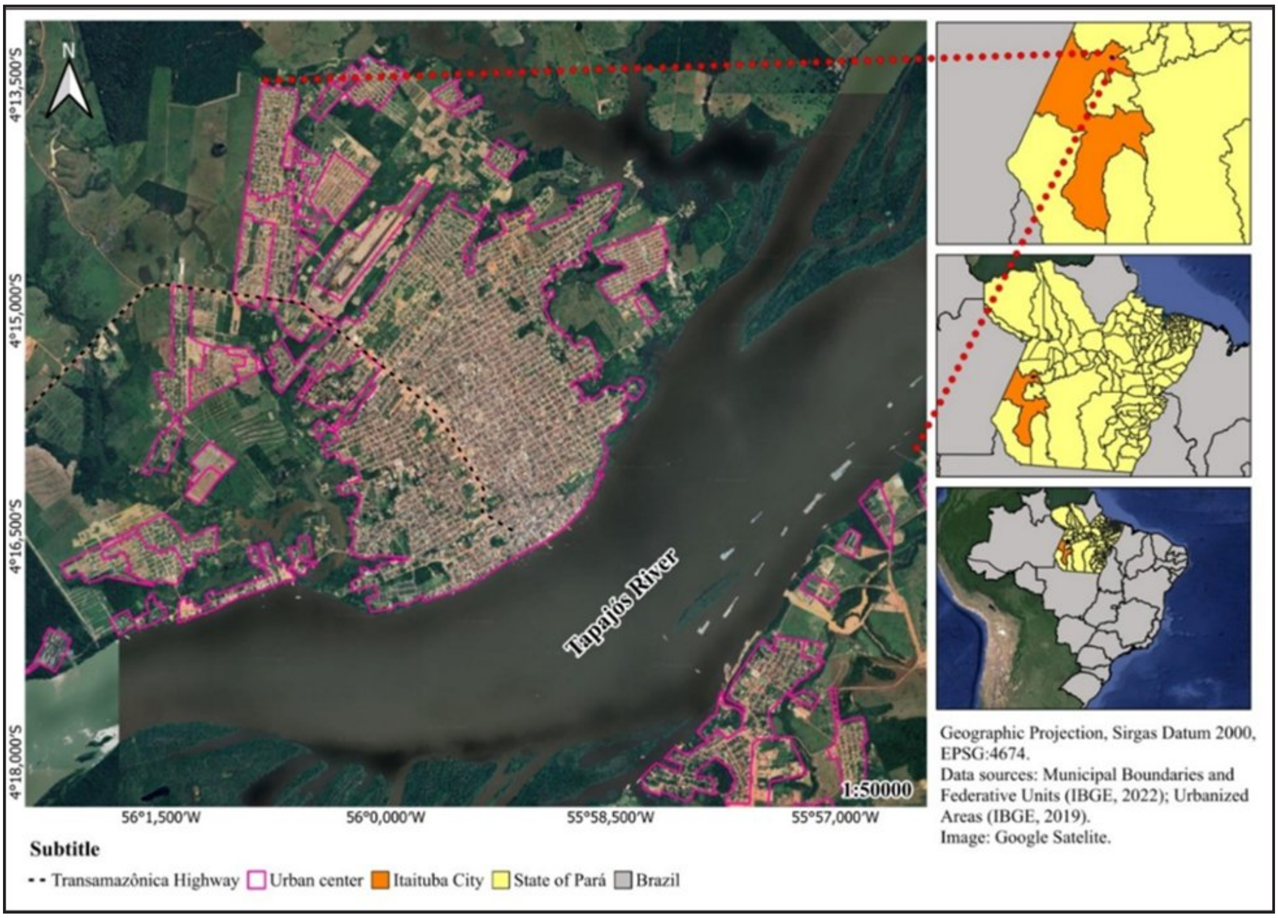
2 METHODOLOGY

2.1 Characterization of the study area

Located in the southwestern mesoregion of Pará, more precisely on the left bank of the Tapajós River, Amazon River tributary, the city of Itaituba (Figure 1) has a total population of 123,314 inhabitants and a territorial area of 62,042.472 km² (IBGE, 2022).

In topographical terms, it has flat to gently undulating terrain, characteristic of the Tapajós Residual Plateau. The region's climate has a minimum temperature of over 18ºC and relative humidity of over 80% almost every month of the year. Another relevant factor is that the most intense rainy seasons occur between December and June, with rainfall rates close to 2065 mm/year. According to climatological water balance, water surplus in the soil increases from February to April, which adds up to 884 mm (Silva Junior et al., 2023; Pontes et al., 2013).

Figure 1 – Location map of the city of Itaituba-PA



Source: Authors (2024)

In 2019, its urban core had an area of 33.42 km², with 2.3% urbanization of public roads in 2010 (IBGE, 2022). The current reality shows a different urban scenario, which was (and is still being) designed by a process of unplanned occupation, promoting impacts on the city's infrastructure, such as irregular occupation of banks of watercourses, increased surface runoff, silting up and eutrophication of streams, discharge of domestic effluents into urban drainage systems, irregular disposal of solid urban waste, among others.

According to mapping by the Geological Survey of Brazil (CPRM, 2022), the city has some riverside areas categorized as “high” and “very high” risks of flooding, which could affect 910 homes and 3,630 people. In this regard, Silva Junior et al. (2023) reported the impacts of an extreme rainfall event in May 2023 with 173.4 mm of rainfall between 9 a.m. and 3 p.m. (104 mm of which occurred in just 2 hours), which caused flooding of places near the streams and left several flooded roads in the city.

2.2 SUDS dimensioning

2.2.1 Rain garden

The rain garden was dimensioned in two stages. In the first, the garden surface area was defined, considering a percentage of 5% of the impermeable areas inflowing to the system, as suggested by Melo et al. (2014). Supporting this premise, Dussaillant et al. (2005) suggested a garden area of between 5% and 20% of the rain catchment area. Thus, three impermeable areas were adopted for verification, 100 m², 250 m² and 500 m², and the garden was dimensioned with areas of 5 m², 12.5 m² and 25 m². In the second stage, the gravel layer height was dimensioned (Equation 1), adding a safety margin for storage equivalent to 5 cm in height, as recommended by Melo et al. (2014). For dimensioning, the rainfall intensities calculated by the municipality’s Intensity-Duration-Frequency (IDF) equation (CPRM, 2014) were considered for durations of 5, 10, 15, 30 and 60 minutes, respectively, with a Return Time (RT) of 5 years, generally adopted in microdrainage dimensioning and also used in the rain garden construction by Barros et al. (2024)

in the city of Recife-PE. It was also considered the runoff coefficient (C) of 0.70 for urbanized areas (Rodrigues & Silva Junior, 2024) and effective porosities of 25% and 30% for sand and gravel, respectively (Medeiros, 2019).

$$h_g = \frac{V_i - V_o - (h_s \times A_{RG} \times \eta_s)}{(A_{RG} \times \eta_g)} \tag{1}$$

Where:
h_g - gravel layer height, in meters;
V_i - inflow volume, in m³ (Equation 2);
V_o - outflow volume, in m³ (Equation 3);
A_{rg} - rain garden area, in m² (5 m², 12.5 m² and 25 m²);
h_s - sand layer height, in meters;
n_s and n_g - sand and gravel porosity, respectively.

$$V_i = 0.2778 \times c \times i \times A_c \times t_d \tag{2}$$

Where:
c - runoff coefficient;
i - rainfall intensity, in mm/h;
A_c - contribution area, in km²;
t_d - rainfall duration time, in seconds.

$$Vo = A_{inf} \times inf \times t_d \tag{3}$$

Where:
A_{inf} - infiltration area, in m², which is equal to A_{RG};
inf - infiltration, in m/s, which, in this study, will be equivalent to hydraulic conductivity of $k=10^{-4}$ m/s;
t_d - rainfall duration time, in seconds.

Finally, the total dimensioning volume was obtained, calculated by Equation 4.

$$V_{RG} = A_{RG} \times (h_g + h_s + h_{sub}) \tag{4}$$

Where:
V_{RG} - rain garden dimensioning total volume, in m³;
A_{RG} - rain garden area, in m²;
h_g - gravel layer height, in meters;

h_s - sand layer height, in m²;
h_{sub} - substrate layer height, in m².

2.2.2 Infiltration trench

The procedure adopted for dimensioning this device was based on the equations for trench inflow (Equation 5) and outflow volumes, calculated using Darcy's law (Equation 6). The mean rate at which water leaves the trench (effluent) can be approximated by the mean of outflow volumes for filling and emptying the device, taking into account the time required for each process. However, this volume, in the case of the trench, depends on its lateral area, which in turn depends on the device dimensions. It was therefore necessary to make an arbitrary initial estimate of the device dimensions. In this regard, the total area of the sides of the percolation structure was calculated using Equation 7. To ensure that water percolates through the soil, k = 10^{-4} m/s was adopted for the saturated hydraulic conductivity of a sandy soil with good infiltration conditions (Lima, 2009). Once inflow and outflow volumes were obtained, Equation 8 was applied to calculate trench storage volume, considering an effective porosity of 30% for coarse gravel (Medeiros, 2019). As for rain garden dimensioning, three contribution areas were considered, 100 m², 250 m² and 500 m², as well as rainfall durations of up to 60 minutes, a 5-year RT and a runoff coefficient (C) of 0.70.

$$V_i = 1{,}25 \times c \times i \times t_d \times A_c \qquad (5)$$

Where:
Vi - trench inflow volume, in m³;
c - runoff coefficient;
i - rainfall intensity, in m/h;
t_d - rainfall duration time, in hours;
A_c - contribution area, in m².

$$V_{perc} = k \times \frac{A_{perc}}{2} \times 3600 \times t_d \qquad (6)$$

Where:

V_{perc} - volume of water percolated in the soil, in m³;

K - parameter of saturated hydraulic soil conductivity, in m/s;

A_{perc} - total area of the sides of the structure for percolation, in m² (Equation 7);

t_d - rainfall duration time, in hours.

$$A_{perc} = 2 \times H \times (B + L) \tag{7}$$

Where:

H - height, in meters;

B - breadth, in meters;

L - length, in meters.

$$V_{TCH} = \frac{max(V_i - V_{perc})}{\varnothing} \tag{8}$$

Where:

V_{TCH} - trench volume, in m³;

V_i - trench inflow volume, in m³;

V_{perc} - outflow volume percolated in the soil, in m³;

$\varnothing$ - effective material porosity.

2.3 Cost estimation and budgeting

With the devices dimensioned, the budget for each combination of rain gardens and infiltration trenches was drawn up based on unit prices (in non-exempt values) from the Brazilian National System of Research of Costs and Indexes of Civil Construction (SINAPI - Sistema Nacional de Pesquisa de Custos e Índices da Construção Civil) table in June 2024, for the state of Pará (SINAPI, 2024), and price quotations in the local market of Itaituba-PA for July 2024. In the local market, only inputs were quoted and, subsequently, the prices collected were included in the SINAPI composition.

Table 1 shows the items used in the cost estimate for constructing the SUDS analyzed, considering manual and mechanized excavation and landfilling services.

Table 1 – Cost of (manual and mechanized) services and inputs for constructing a rain garden and infiltration trench in Itaituba-PA

Item	Code	Description	Unit	Unit Price (R$)	
				SINAPI	LOCAL
1		**EXCAVATION**			
1.1		***Mechanized Excavation***			
1.1.1	90082	Mechanized excavation of trenches up to 1.5 m deep (average upstream and downstream/one composition per section), excavator (0.8 m³), breadth of 1.5 m to 2.5 m, in 1st category soil, in places with a high level of interference.	m³	11.36	11.36
1.1.2	90084	Mechanized excavation of trenches with a depth greater than 1.5 m up to 3.0 m (average upstream and downstream/one composition per section), excavator (0.8 m³), breadth up to 1.5 m, in 1st category soil, in places with a high level of interference.	m³	11.00	11.00
1.2	***Manual Excavation***				
1.1	93358	Manual excavation of a trench with a depth of less than or equal to 1.30 m. AF_02/2021.	m³	86.16	86.16
2		**LANDFILLING**			
2.1		***Mechanized Landfilling***			
2.1.1	102716	Sand filling for drainage, mechanized laying	m³	125.84	190.58
2.1.2	102717	Gravel filling for drainage, mechanized laying	m³	267.56	240.08
2.2		***Manual Landfilling***			
2.2.1	94342	Manual landfilling of trenches with sand for landfilling	m³	88.34	199.29
2.2.2	102719	Filling gravel for drain, manual release	m³	276.35	248.79
3		**FILTRATION AND DRAINAGE**			
3.1	103653	100% polyester non-woven geotextile, tensile strength 31 KN/m (RT-31), installed in drain - supply and installation.	m²	37.99	37.99[1]
4		**VEGETATION AND SUBSTRATE**			
4.1	98505	Planting ground cover AF_05/2018	m²	71.54	255.80
4.2	7253	Topsoil (bulk)	m³	194.14	178.57

Source: Organized by the Authors (2024) and SINAPI (2024)

Note: [1]There is no supplier of this input in Itaituba-PA. In this case, it was decided to maintain the SINAPI price

2.3.1 Rain Garden

To determine the total cost (in reais, R$, Brazilian currency) for constructing the garden, associated with rainfall with “ (duration time)” and “RT (Return Time)”, Equation 9 was used. The variables of this equation are represented by Equations 10 to 15, where each item that makes up rain garden construction is priced. This method, used to estimate costs, was adapted from Melo et al. (2014). Finally, the total cost (Equation 8) was divided by the areas of the gardens (5 m², 12.5 m² and 25 m²), as well as by the dimensioned volumes (Equation 4), obtaining cost per m² and m³ of construction, respectively.

$$C_{RG}\,(t_d\,, RT) = C_1 + C_2 + C_3 + C_4 + C_5 + C_6 \qquad (9)$$

Where:
C_{RG} - total rain garden cost, in R$, associated with "$t_d$" and "RT".

$$C_1 = C_e \times A_{RG} \times (h_g + h_s + h_{sub}) \qquad (10)$$
$$C_2 = C_g \times A_{RG} \times h_g \qquad (11)$$
$$C_3 = C_s \times A_{RG} \times h_s \qquad (12)$$
$$C_4 = C_{gtx} \times A_{RG} \qquad (13)$$
$$C_5 = C_{sub} \times A_{RG} \times h_{sub} \qquad (14)$$
$$C_6 = C_{veg} \times A_{RG} \qquad (15)$$

Where:
C_e - cost per cubic meter of excavation, with material and labor included, in R$;
C_g - cost per cubic meter of gravel for storage layer, in R$;
C_s - cost per cubic meter of sand for storage layer, in R$;
C_{gtx} - cost per square meter of geotextile, in R$;
C_{sub} - cost per cubic meter of planting substrate, in R$;
C_{veg} - cost per square meter of planting, in R$;
A_{RG} - rain garden area, in m²;
h_g - gravel layer height, in meters;
h_s - sand layer height, in meters;
h_{sub} - substrate layer height, in meters.

For vegetation cover, the creeping seedling/creeping peanut/eleven o'clock groundcover species was chosen. Table 1 presents the costs of items that make up rain gardens based on SINAPI unit prices (June 2024 reference) and local market price unit prices (July 2024 reference).

2.3.2 Infiltration trench

The total cost was obtained by adding the costs of each item that makes up the assessed trench (Equation 16) based on Equations 17 to 19. The method used was proposed by Melo et al. (2016), contemplating some adaptations in the calculation equations. Finally, the total cost (Equation 16) was divided by the dimensioned volumes (Equation 8) and the surface areas of the trenches, obtaining the cost per m³ and m² of construction, respectively.

$$C_{TCH}\,(t_d, RT) = X_1 + X_2 + X_3 \quad (16)$$

Where:
$C_{TCH}\,(t_d, RT)$ - total infiltration trench cost, associated with "t_d" and "RT", in R$.

$$X_1 = C_g \times L \times B \times H \quad (17)$$
$$X_2 = C_e \times L \times B \times H \quad (18)$$
$$X_3 = C_{gtx} \times (2 \times L \times H + 2 \times B \times H + L \times B) \quad (19)$$

Where:
C_g - storage layer material cost (with gravel number 02) (R$/m³);
C_e - excavation cost (R$/m³);
C_{gtx} - geotextile cost (R$/m²);
L and B - trench length and breadth, in meters, respectively;
H - storage layer height, in meters.

Table 1 shows the costs of items that make up the infiltration trenches based on SINAPI unit prices (June 2024 reference) and local market prices (July 2024 reference).

3 RESULTS AND DISCUSSION

3.1 SUDS dimensioning

3.1.1 Rain Garden

Table 2 shows the dimensions assigned to the 5 m², 12.5 m² and 25 m² areas of assessed rain gardens, considering the input areas of 100 m², 250 m² and 500 m². Breadth was set at 1.25 m, since the construction of this system normally occurs on sidewalks.

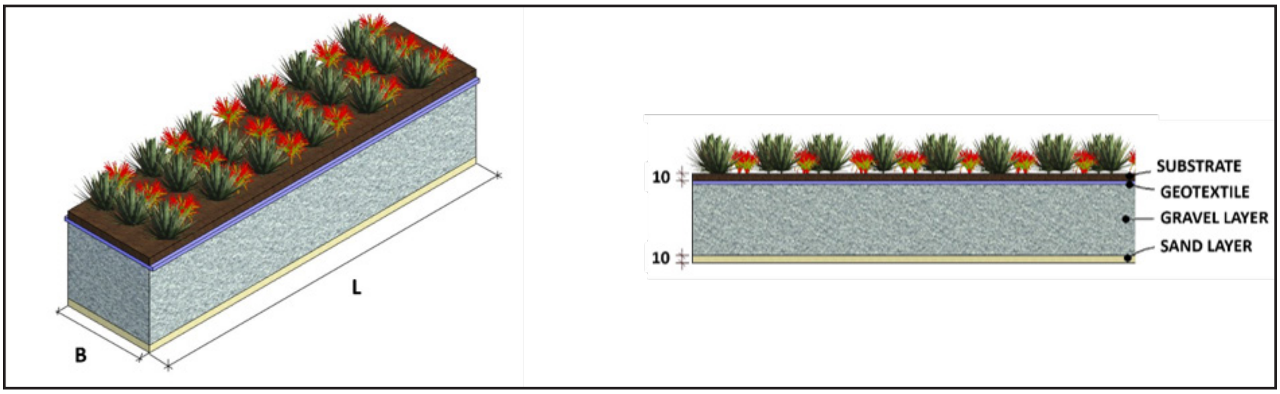
Table 2 – Plan dimensions assigned to the proposed rain gardens

Rain Garden	A_{RG} (m²)	L (m)	B (m)
RG1	5.0	4.0	
RG2	12.5	10.0	1.25
RG3	25.0	20.0	

Source: Authors (2024)

Based on the adopted dimensions, a profile was defined for the proposed rain garden, considering the layers illustrated in Figure 2.

Figure 2 – Arrangement of component layers of the proposed rain garden with dimensions in centimeters (cm)



Source: Authors (2024)

For analysis purposes, substrate and sand layer fixed heights were considered in the amount of 10 cm, according to Melo et al. (2014). The substrate layer will be used for planting vegetation, and the sand layer will be used to level the garden bottom. A geotextile blanket will be placed below the substrate layer to retain the substrate fines during the infiltration process, preserving the voids in the storage layer, which is made of gravel number 02. Table 3 shows the result of the dimensioning of this layer as well as the total volumes calculated for the three proposed rain gardens (5 m², 12.5 m² and 25 m²), considering a rain with 5-year RT and durations of 5, 10, 15, 30 and 60 minutes.

Table 3 shows that the gravel layer ranged from 0.46 to 1.82 m, with a storage capacity equivalent to 58% of the inflow volume for rainfall lasting 60 minutes. On average, the storage volume accounted for around 26% of the total volumes, which ranged from 3.31 m³ to 50.57 m³, considering gardens with areas of 5 m², 12.5 m² and 25 m². It is worth noting that the heights dimensioned need to be limited to the water table level so that there is no upwelling of groundwater in the system's storage layer during rain events. With regard to groundwater in Itaituba, Pará (2012) reveals that the mean static level, in relation to the ground surface, observed in the municipality's tube wells is 12.7 m, with maximum and minimum values of 20.4 m and 6.5 m, respectively. Hence, it should be noted that these values validate the total depths calculated for the system, limited to 2.02 m.

Table 3 – Maximum input flow and input volumes for rain gardens

Rain Garden	t_d (min.)	i (mm/h)	V_i (m³)	V_o (m³)	V_{stored} (m³)	Layer: Gravel h_g + 0.05 (m)	Layer: Sand h_s (m)	Layer: Substrate h_{sub} (m)	Total Height (m)	V_{RG} (m³)
RG1 A_{RG}: 5 m²	5	155.47	0.91	0.17	0.74	0.46	0.10	0.10	0.66	3.31
	10	138.76	1.62	0.33	1.29	0.83			1.03	5.13
	15	125.39	2.19	0.50	1.70	1.10			1.30	6.50
	30	97.57	3.42	0.99	2.43	1.58			1.78	8.92
	60	68.06	4.76	1.98	2.78	1.82			2.02	10.11
RG2 A_{RG}:12.5 m²	5	155.47	2.27	0.41	1.85	0.46	0.10	0.10	0.66	8.27
	10	138.76	4.05	0.83	3.22	0.83			1.03	12.83
	15	125.39	5.49	1.24	4.25	1.10			1.30	16.25
	30	97.57	8.54	2.48	6.06	1.58			1.78	22.29
	60	68.06	11.91	4.95	6.96	1.82			2.02	25.29
RG3 A_{RG}: 25 m²	5	155.47	4.53	0.83	3.71	0.46	0.10	0.10	0.66	16.53
	10	138.76	8.10	1.65	6.45	0.83			1.03	25.65
	15	125.39	10.97	2.48	8.50	1.10			1.30	32.49
	30	97.57	17.08	4.95	12.13	1.58			1.78	44.59
	60	68.06	23.82	9.90	13.92	1.82			2.02	50.57

Source: Authors (2024)

3.1.2 Infiltration trench

Table 4 shows infiltration trench volumes for the contribution areas of 100, 250 and 500 m². It was observed that the maximum storage volumes ranged from 2.66 m³ to 14.40 m³, accounting for on average 47% of the inflow volume for rainfall with a

5-year RT and a duration of up to 60 minutes. The storage volume accounted for 30% of the total volumes, which ranged from 8.88 m³ to 47.99 m³.

Table 4 – Trench volume dimensioning for different contribution areas

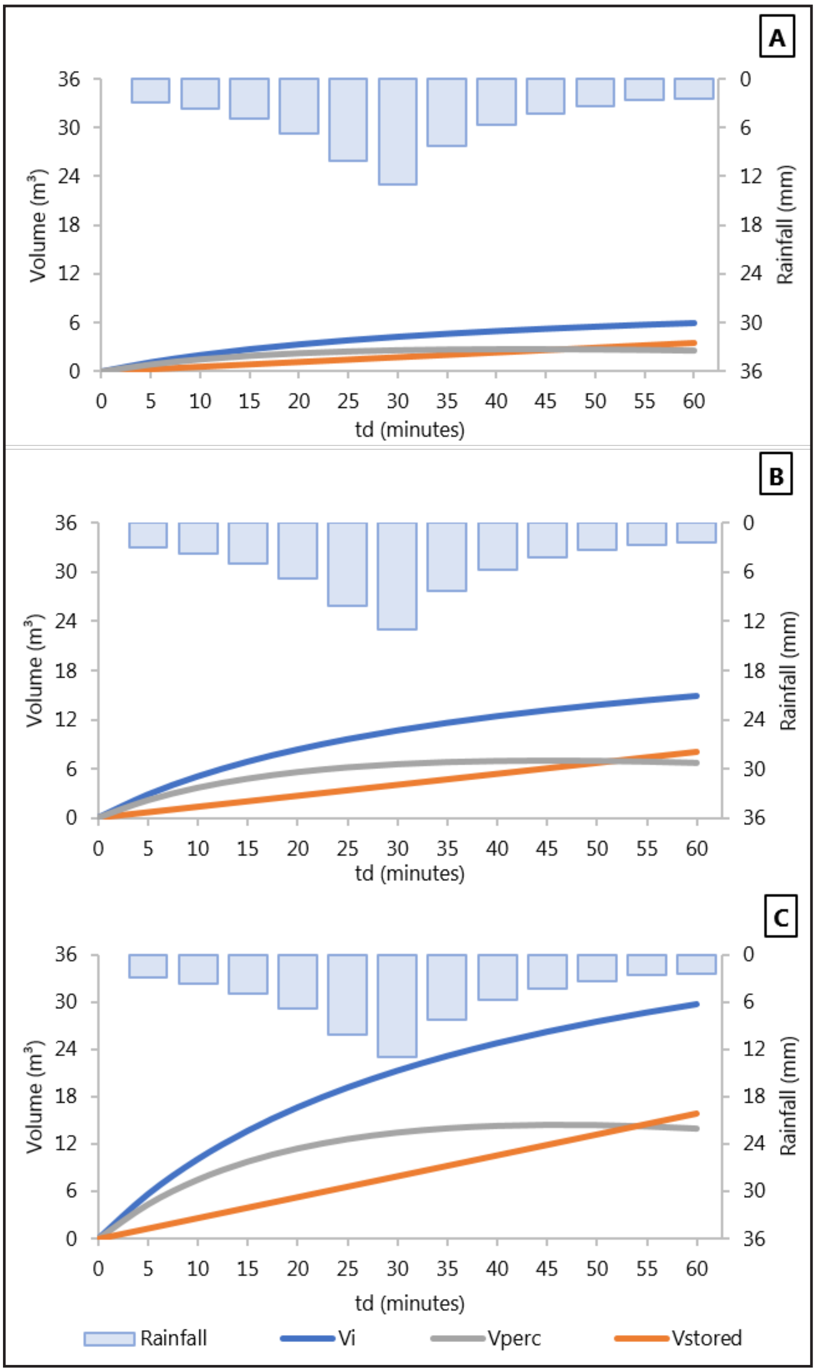
Trench Inflow Area – A_c (m²)	t_d (min.)	i (mm/h)	V_i (m³)	V_{perc} (m³)	$V_{stored} = V_i - V_{perc}$ (m³)	Max ($V_i - V_{perc}$) (m³)	V_{TCH} (m³)
100	5	155.5	1.13	0.29	0.85	2.66	8.88
	10	138.8	2.02	0.58	1.45		
	15	125.4	2.74	0.86	1.88		
	20	114.4	3.34	1.15	2.19		
	25	105.3	3.84	1.44	2.40		
	30	97.6	4.27	1.73	2.54		
	35	90.9	4.64	2.02	2.62		
	40	85.2	4.97	2.30	2.66		
	45	80.1	5.26	2.59	2.66		
	50	75.6	5.51	2.88	2.63		
	55	71.6	5.75	3.17	2.58		
	60	68.1	5.96	3.46	2.50		
250	5	155.5	2.83	0.68	2.16	7.06	23.54
	10	138.8	5.06	1.35	3.71		
	15	125.4	6.86	2.03	4.83		
	20	114.4	8.35	2.70	5.64		
	25	105.3	9.60	3.38	6.22		
	30	97.6	10.67	4.05	6.62		
	35	90.9	11.60	4.73	6.88		
	40	85.2	12.42	5.40	7.02		
	45	80.1	13.14	6.08	7.06		
	50	75.6	13.78	6.75	7.03		
	55	71.6	14.36	7.43	6.94		
	60	68.1	14.89	8.10	6.79		
500	5	155.5	5.67	1.32	4.35	14.40	47.99
	10	138.8	10.12	2.64	7.48		
	15	125.4	13.72	3.96	9.75		
	20	114.4	16.69	5.28	11.41		
	25	105.3	19.20	6.60	12.60		
	30	97.6	21.34	7.92	13.42		
	35	90.9	23.20	9.24	13.96		
	40	85.2	24.84	10.56	14.27		
	45	80.1	26.28	11.88	14.40		
	50	75.6	27.57	13.20	14.36		
	55	71.6	28.73	14.52	14.20		
	60	68.1	29.78	15.85	13.93		

Source: Authors (2024)

Figure 3 shows, graphically, inflow (*V_i*, outflow-percolated (V_{perc}) and stored (V_{stored}) volumes in trenches with volumetric dimensions of 8.88 m³, 23.54 m³ and

47.99 m³. The volumes expressed are derived from Table 4 for a 5-year RT rainfall lasting 60 minutes ($Rainfall_{total}$ 68.1 mm), which is represented in Figure 3, using the alternating block method.

Figure 3 – Inflow (V_i), outflow/percolated (V_{perc}) and stored (V_{stored}) volumes in trenches for rains with a 5-year RT and a 60-minute duration (t_d) for areas of contribution (A_c): a) 100 m²; b) 250 m² and c) 500 m²



Source: Authors (2024)

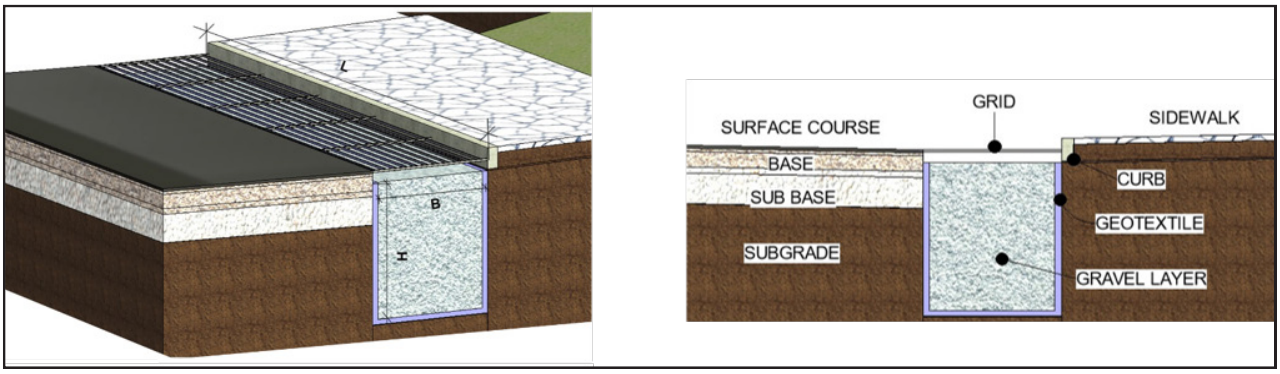
Table 5 shows the dimensions obtained from dimensioning in Table 4 and used to quantify the inflows and services for constructing the trenches analyzed. It is noteworthy that the breadths (B) and heights (H) were set at 1.25 m and 1.30 m, respectively, with variations in the lengths (L) between 5.46 and 29.53 m, respectively, depending on the volume calculated for infiltration trench. With the dimensions adopted, a profile was defined for the proposed infiltration trench, considering the structure in Figure 4.

Table 5 – Infiltration trench dimensioning

Trench	L (m)	H (m)	B (m)	V_{TCH} (m^3)	A_{perc} (m^2)
TCH1	5.46	1.30	1.25	8.88	17.46
TCH2	14.49	1.30	1.25	23.54	40.92
TCH3	29.53	1.30	1.25	47.99	80.03

Source: Authors (2024)

Figure 4 – Structure of the proposed infiltration trench



Source: Authors (2024)

Table 6 shows the budget for dimensioning rain gardens, considering a 5-year RT and rainfall durations of up to 60 minutes. It can be seen that the cost of a rain garden varies, depending on the area, the rainfall duration time and the method of excavation and landfilling. Moreover, Siwiec et al. (2018) attribute other aspects that can also vary the costs of rain garden installation, such as the location where it will be installed, the type of vegetation cover, the type of soil and whether it will have equipment for monitoring and irrigating the garden.

3.2 SUDS economic analysis

3.2.1 Rain Garden

On average, in Itaituba-PA, a rain garden would cost R$575.35/m², carried out manually, and R$467.01/m² for mechanized excavation and landfilling, based on SINAPI prices. Based on local quotation, the costs ranged from R$736.92/m² (manual) to R$624.05/m² (mechanized), accounting for, on average, an increase of 31% in relation to the costs budgeted by SINAPI (Table 6). In the Amazon, Xavier and Pinheiro (2021) found a 19.8% increase in prices in the local market of Manaus-AM when compared to SINAPI prices.

Table 6 – Cost estimate for rain gardens in Itaituba-PA

t_d (minutes)		RG1 A_{RG}: 5 m² V_{RG}: 3.31 to 10.11 m³		RG2 A_{RG}: 12.5 m² V_{RG}: 8.27 to 25.29 m³		RG3 A_{RG}: 25 m² V_{RG}: 16.53 to 50.57 m³	
		Manual BRL ($)	**Mechanized BRL ($)**	**Manual BRL ($)**	**Mechanized BRL ($)**	**Mechanized BRL ($)**	**Manual BRL ($)**
SINAPI	5	1,612.70	1,363.84	4,031.75	3,409.61	8,063.50	6,819.22
	10	2,273.74	1,872.46	5,684.34	4,681.14	11,368.69	9,362.28
	15	2,769.84	2,254.17	6,924.61	5,635.42	13,849.22	11,270.83
	30	3,646.74[1]	2,925.65	9,116.84[1]	7,314.12	18,233.69[1]	14,628.25
	60	4,080.74[1]	3,259.15	10,201.9[1]	8,147.87	20,403.71[1]	16,295.74
LOCAL	5	2,516.63	2,244.85	6,291.58	5,612.12	12,583.17	11,224.25
	10	3,127.42	2,703.35	7,818.55	6,758.37	15,637.10	13,516.75
	15	3,585.81	3,047.45	8,964.53	7,618.63	17,929.06	15,237.26
	30	4,396.04[1]	3,652.46	10,990.1[1]	9,131.15	21,980.22[1]	18,262.29
	60	4,797.06[1]	3,953.06	11,992.6[1]	9,882.64	23,985.28[1]	19,765.28
SINAPI:						**BRL $/m²**	**BRL $/m³**
Mean Cost of Manual Service						575.35	433.91
Mean Cost of Mechanized Service						467.01	354.93
LOCAL:						**BRL $/m²**	**BRL $/m³**
Mean Cost of Manual Service						736.92	577.95
Mean Cost of Mechanized Service						624.05	495.04

Note: [1] Even with depths greater than 1.30 m, as shown in Table 3, for budgeting purposes, the cost for manual trench excavation shown in Table 1 was used.
Source: Authors (2024)

In the United States, the Environmental Protection Agency (EPA) estimates that the cost of installing a rain garden can vary between US$54/m^2 and US$70/m^2 (Meng & Hsu, 2019), equivalent to R$291/m² and R$378/m² (considering US$1= R$5.40), respectively. In China, Han et al. (2021) reported that this cost can reach US$50/m², equivalent to R$270/m². In Brazil, Melo et al. (2014) budgeted a rain garden, dimensioned for rainfall with a 2-year RT and a 60-minute duration, at R$2,157.52/m^2.

Considering the cost in cubic meters according to SINAPI, the budget varied from R$433.91/m³ to R$354.93/m³ for manual and mechanical services, respectively. Supporting these figures, Melo et al. (2014) budgeted R$300.55/m³ for a rain garden in Recife-PE for rainfall with a 2-year RT and a 60-minute duration. Through local quotations in Itaituba-PA, the cost of creating a rain garden can vary from R$577.95/m³ to R$495.04/m³ for manual and mechanized services, respectively, revealing, on average, a 36% increase in the SINAPI budget. This percentage increase is due to the cost of gardening inflows (sand and eleven o'clock seedlings) quoted on the local market, which had higher prices than those specified by SINAPI.

3.2.2 Infiltration trench

Table 7 shows the costs of making infiltration trenches, considering a 5-year RT and a rainfall duration of up to 60 minutes. On average, the cubic meter of an infiltration trench in Itaituba-PA would cost R$459.76/m³ for manual excavation and landfilling services, and R$376.17/m³ for mechanized services. Through quotations on the local market, values per cubic meter would be, on average, 7% cheaper, ranging from R$432.20/m³ to R$348.69/m³ for manual and mechanized services, respectively. This saving is due to the storage layer inflow cost (made up of gravel), which was lower in the local market than in SINAPI, on average 11.36%.

In comparison to the results obtained, Melo et al. (2016) budgeted a 4.5 m² infiltration trench in Recife-PE with an approximate value of R$4,000.00, considering rainfall with a 5-year RT and 60-minute duration equivalent to R$888.89/m². Silva (2023) made a cost estimate, using SINAPI, for implementing infiltration trenches in the city of Porto Alegre-RS, arriving at a value of R$573.77/m³.

Table 7 – Cost estimate for infiltration trenches in Itaituba-PA

Trench		Manual BRL ($)		Mechanized BRL ($)	
		SINAPI	LOCAL	SINAPI	LOCAL
TCH1 - Volume: 8.88 m³		4,141.32	3,896.64	3,399.14	3,155.13
TCH2 - Volume: 23.54 m³		10,777.47	10,128.65	8,809.44	8,162.43
TCH3 - Volume: 47.99 m³		21,837.72	20,515.34	17,826.62	16,507.92
Mean Cost	BRL $/m²	597.69	561.86	489.02	453.29
	BRL $/m³	459.76	432.20	376.17	348.69

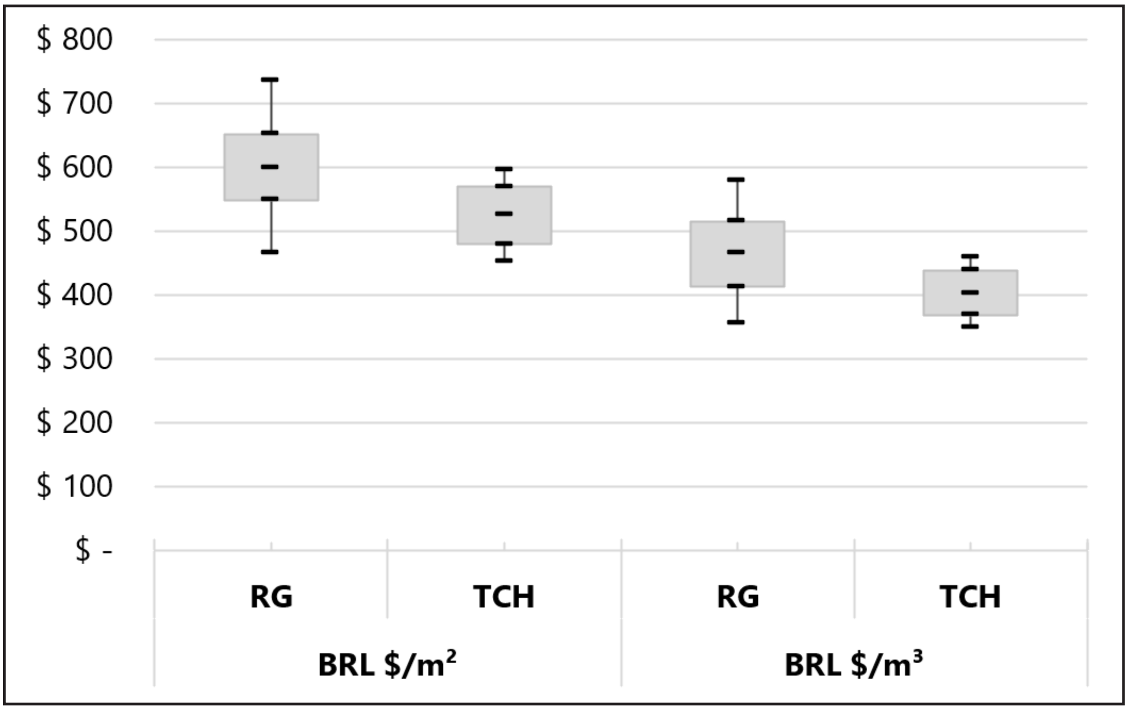
Source: Authors (2024)

3.2.3 Cost comparison between the systems adopted

Figure 5 shows the comparison of costs, per m² and m³, for rain garden and infiltration trench devices in Itaituba-PA. Among the devices assessed, and grouping the costs estimated using SINAPI and the local market, it was observed that an infiltration trench would be the most economically viable option when compared to a rain garden, accounting for an average saving of 13% (including manual and mechanized services). In this respect, an infiltration trench varies at a mean cost of R$525.47±72.18/m² or R$404.21±55.52/m³, and a rain garden would cost R$600.83±133.83/m² or R$465.46±110.53/m³. By assessing only costs per local quotation, these savings tend to be greater, averaging 27%.

When assessing the difference in cost in terms of how the SUDS analyzed are constructed, manual excavation and landfilling are, on average, 21% more expensive than mechanized services. However, in small areas or places with space restrictions, manual work may be the only viable option.

Figure 5 – Cost for constructing the dimensioned devices in R$/m² and R$/m³



Source: Authors (2024)

4 CONCLUSIONS

As far as the technical aspect is concerned, the rain garden and infiltration trench designed are able to store a maximum of 58% and 47% of inflow volume, respectively, which is the result of surface runoff from the contributing areas of 100 m², 250 m² and 500 m², considering a rainfall with a 5-year RT and a 60-minute duration. This accounts for, on average, 26% to 30% of the total volume of the dimensioned devices.

In terms of economic viability, grouping together the costs estimated by SINAPI and by local market quotations, an infiltration trench proved to be the least expensive option, saving an average of 13% compared to a rain garden (including manual and mechanized services). When only costs per quote on the local market are assessed, the savings with the use of infiltration trenches are even greater, averaging 27%. In terms of how the devices analyzed are constructed, manual excavation and landfilling is, on average, 21% more expensive than mechanized services.

For Itaituba-PA, a city in the countryside of the Amazon in the midst of urban development, the use of SUDS is an alternative for controlling flooding at critical points during the Amazonian winter. However, culturally, there is still resistance from the city's public bodies to the use of these techniques in public urban infrastructure projects. Despite this situation, it is hoped that this study can help guide decisions and actions in local urban planning, with a view to construct a more resilient, sustainable city that is prepared to face the present and future challenges related to urban drainage.

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