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Development of an index for performance evaluation of urban drainage systems in small municipalities

Desenvolvimento de um índice para avaliação de desempenho de sistemas de drenagem urbana em municípios de pequeno porte

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Abstract

Urbanization intensifies extreme events and increases population vulnerability, especially in small municipalities, where the lack of planning, limited resources, and the absence or inefficiency of urban drainage systems exacerbate the impacts. Thus, evaluating and monitoring the performance of these services is essential for identifying critical areas. This study developed a performance index for stormwater drainage adapted to the limitations of municipalities in Paraíba, incorporating indicators related to infrastructure, maintenance, urbanization, health, risk management, and legislation. The methodology comprised five steps: characterization of the study area, selection of indicators, definition of nominal classification, application of the Analytic Hierarchy Process method, and application of the Stormwater Drainage and Management Service Performance Index (IDDAP-PB). The municipalities of Areia, Cabaceiras, Natuba, Nova Olinda, São Bento, São José de Piranhas, São José dos Ramos, and Serra Grande were selected as case studies. Consultation with specialists indicated greater importance attributed to the indicators of risk management, existing systems, and urbanization. The results revealed precarious infrastructure and weak risk management policies as the main challenges faced by the municipalities of Paraíba. The index proved to be robust in assessing drainage system performance and consistent with local conditions, but it was considered sensitive when comparing municipalities. Among the municipalities analyzed, Serra Grande showed the best performance, while Natuba had the poorest result. The IDDAP-PB can guide public policies and investments, reducing vulnerabilities and supporting informed decision-making. The methodology is replicable but depends on data quality and periodicity to ensure its effectiveness.

Keywords:
Urban sustainability, Flood vulnerability, Analytic Hierarchy Process.

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Resumo

A urbanização intensifica eventos extremos e aumenta a vulnerabilidade das populações, sobretudo em municípios pequenos, onde a falta de planejamento, os recursos limitados e a ausência/ineficiência da drenagem urbana agravam os impactos. Assim, é essencial avaliar e monitorar o desempenho desses serviços para identificar áreas críticas. Este trabalho desenvolveu um índice de desempenho para drenagem de águas pluviais adaptado às limitações dos municípios paraibanos, agregando indicadores relacionados a infraestrutura, manutenção, urbanização, saúde, gestão de riscos e legislação. A metodologia envolveu cinco etapas: caracterização da área de estudo, seleção de indicadores, definição da classificação nominal, aplicação do método *Analytic Hierarchy Process* e aplicação do Índice de Desempenho do Serviço de Drenagem e Manejo de Águas Pluviais (IDDAP-PB). Os municípios de Areia, Cabaceiras, Natuba, Nova Olinda, São Bento, São José de Piranhas, São José dos Ramos e Serra Grande foram selecionados como estudos de caso. A consulta aos especialistas indicou maior importância atribuída aos indicadores de gestão de risco, sistema existente e urbanização. Foi possível constatar a precária infraestrutura e políticas de gestão de risco como os principais problemas enfrentados pelos municípios paraibanos. O índice se mostrou robusto na avaliação do desempenho dos sistemas de drenagem e coerente com a realidade, mas foi considerado sensível quanto à comparação entre municípios. Dentre os municípios, Serra Grande obteve melhor desempenho e Natuba o pior resultado. O IDDAP-PB pode direcionar políticas públicas e investimentos, reduzindo vulnerabilidades e apoiando decisões. A metodologia é replicável, mas depende da periodicidade e qualidade dos dados para garantir sua eficácia.

Palavras-chave:
Sustentabilidade urbana, Vulnerabilidade a inundações, Processo Analítico Hierárquico.

I. INTRODUCTION

Urban flooding has become a global issue, intensified by climate change and rapid urban development. In recent decades, the frequency of such events has increased significantly, posing a challenge to the sustainability of cities (Zabin et al., 2022). To mitigate these impacts, urban flood management has focused on implementing and improving urban drainage systems, aiming to reduce the damage caused by extreme events and promote resilience in urban areas (Li et al., 2024; Luo; Zhang, 2022; Tang et al., 2024).

Recent studies highlight that urban floods accounted for 43.31% of all flood disasters in China between 2008 and 2018, revealing an increase in both the magnitude and frequency of these events, which makes risk management more complex (Kuriqi; Hysa, 2021). In 2022, Brazil had 425 thousand hectares of urbanized areas located within 3 meters of the nearest river, 68% of which had been occupied over the past 38 years (MapBiomas, 2023). These data reinforce the urgency of effective policies and strategies to mitigate the impacts of urban flooding.

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In the context of small municipalities, which are predominant in the national territory, there are significant deficiencies in basic sanitation services (Ferreira, 2020). Such deficiencies are exacerbated by management and planning challenges, as well as the lack of financial, administrative, and institutional resources (Akaishi, 2012). In order to provide greater visibility to municipalities of this typology, municipalities in the state of Paraíba were chosen as analysis units for this study, considering that these localities lack investment, planning, and adequate technical capacity in the field of drainage, and therefore require support for decision-making.

Small and medium-sized municipalities also experience flooding, resulting from unplanned urban expansion, technical deficiencies in management, and insufficient or non-existent stormwater drainage systems (Moreti et al., 2021). To mitigate these problems, it is essential that urban growth be accompanied by effective planning measures. In this scenario, the use of indicators to create performance indices has become a common global practice, especially in Environmental Sanitation, aimed at improving service provision, regulation, and planning (Von Sperling; Von Sperling, 2013). This approach helps identify critical areas and direct investments to reduce vulnerabilities and promote urban sustainability.

However, it is crucial that the instruments used to assess performance accurately reflect reality and preserve the specific characteristics of the studied area, highlighting both local issues and potentialities. Therefore, it is necessary to develop performance assessment methodologies adapted to system limitations, particularly regarding data availability. These methodologies should be directed toward essential services, such as basic sanitation, ensuring applicability and effectiveness even in contexts with information constraints. This approach enables a more precise analysis and solution-oriented strategies tailored to the specific needs of each region.

In the scientific literature, several studies have proposed methodologies and indices for evaluating urban stormwater drainage systems, differing mainly in the selected indicators, assigned weights, and analytical techniques employed. Steiner (2011) developed an urban drainage quality index based on System Fragility Indicators (IFG). The São Paulo Drainage and Stormwater Management Manual (2012) proposed eight areas of analysis for monitoring municipal management, including impermeability, extreme events, and the application of new technologies. Araújo (2016) and Mendonça and Souza (2019) incorporated multicriteria decision support methods, such as AHP, PROMETHEE, ELECTRE-TRI, and TOPSIS, structuring the evaluation into environmental, social, economic, technical, and legal dimensions.

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In this context, the present study aimed to develop a performance index for Urban Drainage and Stormwater Management services, focusing on small municipalities in the state of Paraíba. This index was conceived as a management tool, bringing together representative regional indicators supported by a multicriteria decision model. The proposal seeks to assist in the evaluation and planning of more efficient drainage systems, contributing to more resilient cities and mitigating damage caused by adverse events, such as floods and inundations.

II. MATERIALS AND METHODS

To meet the objectives, the study was divided into five general methodological stages: (i) characterization of the study area; (ii) selection of indicators; (iii) definition of nominal classification; (iv) application of the Analytic Hierarchy Process (AHP) method; and (v) application of the performance index for drainage and urban stormwater management services, in addition to the analysis of index robustness, as presented in the flowchart in Figure 1.

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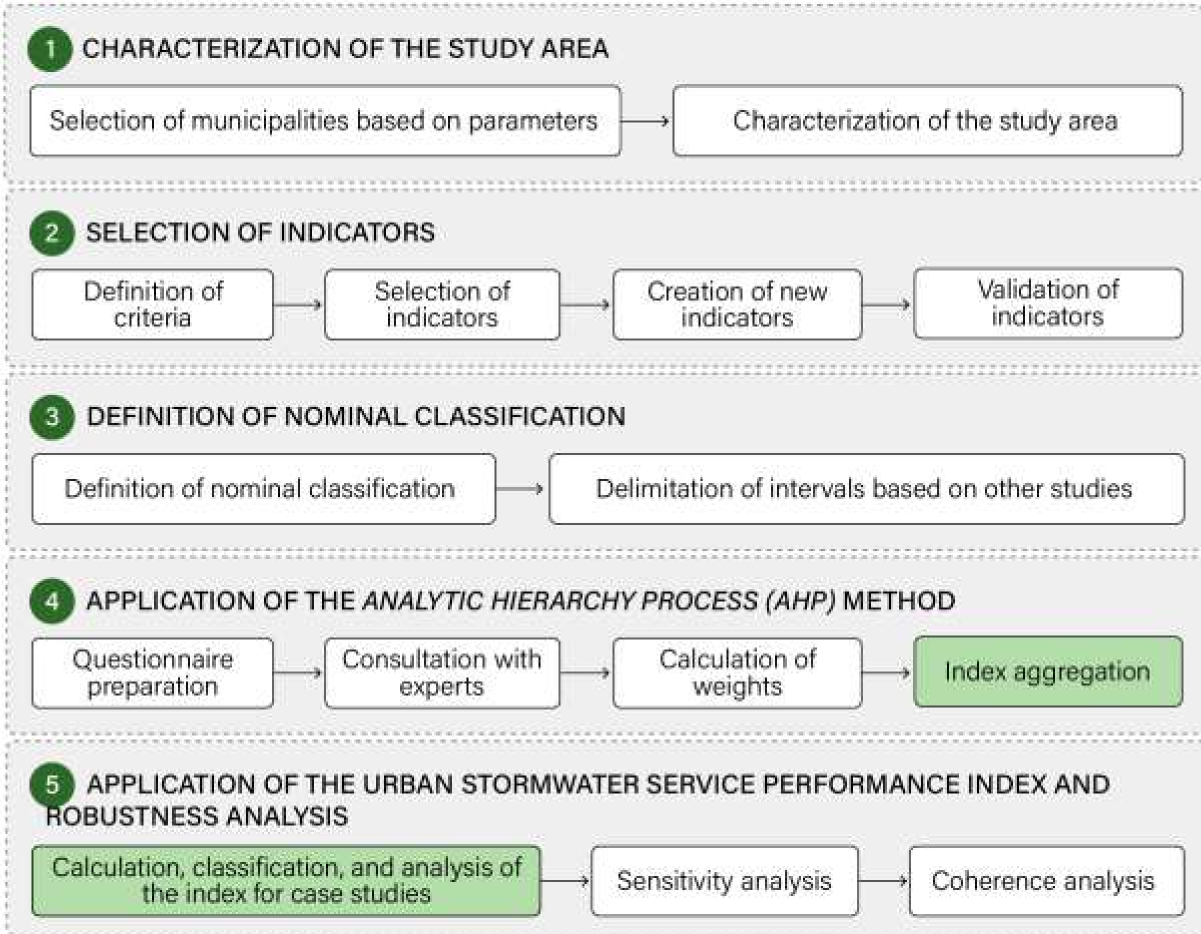

Figure 1 – Methodological flowchart of the study, in which the boxes highlighted in green represent the main product of each methodological stage. Source: Authors (2025).

Characterization of the study area

Considering the relevance of the study's parameterization, efforts were made to diversify the sample of municipalities to ensure greater scope and applicability of the research. The case studies were selected based on geographical and demographic criteria, characteristics of the drainage system, and availability of indicators related to the theme, as described below. Municipalities in the state of Paraíba were chosen as units of analysis, given that these locations face shortages in investment, planning, and technical capacity in the drainage sector, thus requiring support for more informed and effective decision-making.

The state of Paraíba is divided into four intermediate geographic regions (IBGE, 2017), considering geoeconomic aspects. To ensure the geographical decentralization of the study, two municipalities were selected from each intermediate region. Additionally, the sample was limited to small municipalities, defined as those with fewer than 50,000 inhabitants, according to the latest Demographic Census (IBGE, 2022). The

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selection included municipalities with separate and combined drainage systems, covering different realities. The selected municipalities, along with a summary of the selection criteria, are detailed in Table 1.

Table 1 – Municipalities selected as case studies and criteria considered.

Intermediate region	**Municipality**	**Criteria**		
		Estimated population	**Type of drainage system**	**Availability of indicators**
Sousa – Cajazeiras	Serra Grande	2,909	Separador	Excellent
	São José de Piranhas	20,251	Unitário	Good
Patos	Nova Olinda	5,949	Unitário	Excellent
	São Bento	34,031	Unitário	Excellent
Campina Grande	Areia	22,819	Separador	Excellent
	Cabaceiras	5,611	Unitário	Good
João Pessoa	São José dos Ramos	5,957	Separador	Excellent
	Natuba	10,454	Unitário	Excellent

Source: Authors (2025).

The selected municipalities (Figure 2) belong to the group of 49 participants of the Decentralized Execution Term (TED) No. 03/2019, resulting from the partnership between the Federal University of Campina Grande (UFCG) and the National Health Foundation (Funasa) for the development of Municipal Basic Sanitation Plans. They were chosen, in addition to the previously described characteristics, based on the ease of obtaining updated data during field visits. Table 2 presents a summary of the basic physical information related to the selected municipalities, which directly or indirectly affect the soil's infiltration capacity and surface runoff.

Regarding the deep drainage network, the cities of São José de Piranhas, Cabaceiras, and Nova Olinda have the highest coverage. The city of Areia has a separate system consisting of 46 storm drains and approximately 2.75 km of underground galleries that discharge into the streams formed by the existing valleys in the municipality. A large portion of rainwater is directed to the northern part of the municipality through three large galleries.

The municipality of Cabaceiras has underground galleries and storm drains as drainage devices. The system operates under a combined regime, given that the network is shared with the sewage collection service. All water collected by the storm drains is directed to the Taperoá River, which surrounds the urban area. The city of Natuba, on the other hand, does not have an underground stormwater drainage system.

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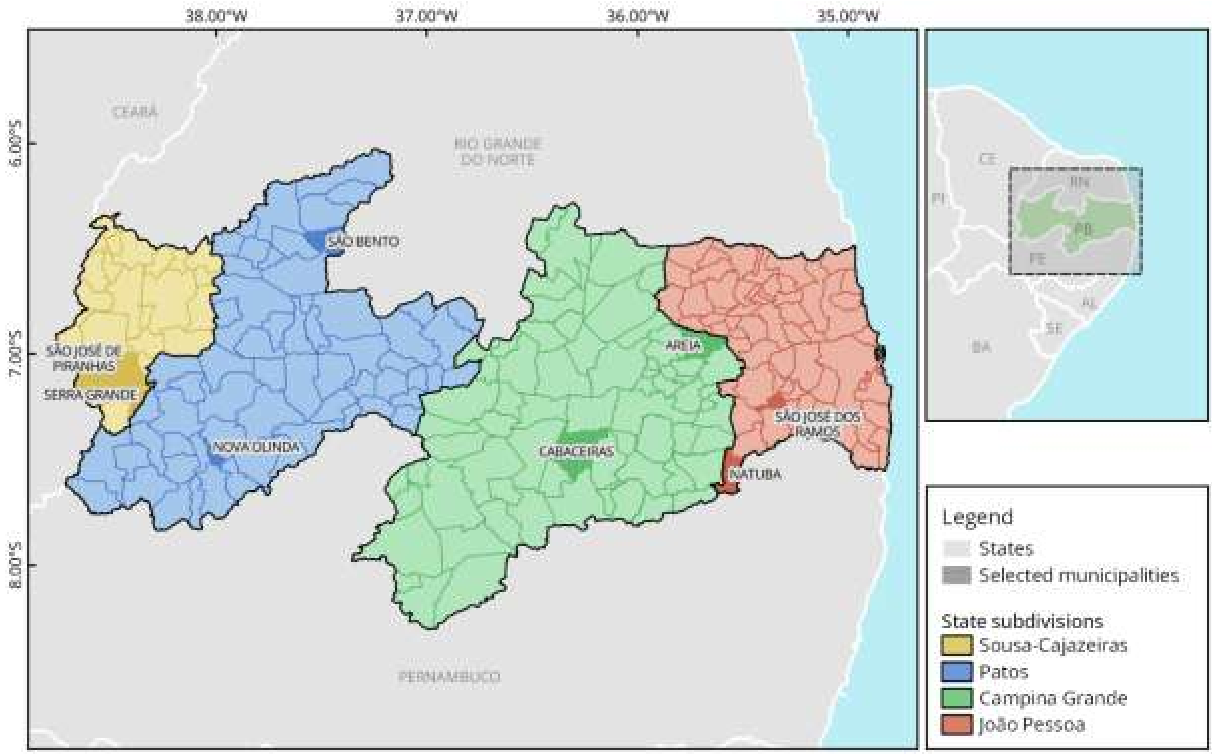

Figure 2 – Location of the municipalities selected as case studies in Paraíba. Source: Authors (2025).

Table 2 – Summary of basic physical information of the selected municipalities.

Municipality	Urban area (km²)	Soil	Climate	Average slope	Predominant relief
Areia	2.773	Eutrophic Red Argisol	Warm climate with winter rainfall	18.86%	Strongly undulating
Cabaceiras	0.579	Orthic Chromic Luvisol	Hot semi-arid	5.26%	Slightly undulating
Natuba	0.615	Eutrophic Red Nitossol	Warm climate with winter rainfall	14.03%	Undulating
Nova Olinda	0.695	Orthic Chromic Luvisol	Warm climate with winter rainfall	2.43%	Flat
São Bento	5.369	Eutrophic Fluvial Neosol and Orthic Chromic Luvisol	Hot semi-arid	3.12%	Flat and slightly undulating
São José de Piranhas	2.278	Orthic Chromic Luvisol	Warm climate with winter rainfall	4.85%	Slightly undulating
São José dos Ramos	1.159	Orthic Chromic Luvisol	Warm climate with winter rainfall	4.05%	Slightly undulating
Serra Grande	0.415	Eutrophic Red Argisol	Warm climate with winter rainfall	10.90%	Undulating

Source: AESA (2020), EMBRAPA (2015), OpenStreetMap (2020), INPE (2008), and IBGE (2019).

The stormwater network of Nova Olinda consists of storm drains, underground galleries, and two open drainage channels. The main channel is 2.72 km long, starting in Nova Olinda and ending in Pedra Branca/PB. The secondary channel, with a length of 600 meters, runs along the eastern perimeter of the urban area. A total of 2.66 km of underground conduits and 39 storm drains forming a combined system were mapped.

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São Bento has a small-coverage combined system composed of two underground channels, galleries, and storm drains. The main galleries direct water to an existing reservoir to the west of the municipality, which then discharges into the Piranhas River. The two existing underground channels convey rainwater to the Piranhas River and São Bento de Baixo. It is worth noting that the entire network is concentrated in the lowest region of the municipality.

The municipality of São José de Piranhas is covered almost entirely by a stormwater drainage network. The combined system consists of underground galleries and storm drains. All water is directed to the streams and reservoirs surrounding the urban area, mainly to Riacho dos Patos and Riacho das Varas, which discharge into the Piranhas River.

São José dos Ramos has a combined system with only one underground gallery of 177 meters and 5 storm drains. The channel that runs through the central region of the municipality (previously open) is 274 meters long. All water collected by the network discharges into the Curimatã Stream. Serra Grande has a separate drainage system composed of 4 storm drains and their outlets. The storm drains are directly connected to their discharge points along the urban area, with no underground galleries.

Non-urbanized, green, and expanding areas of a city directly affect water runoff. Thus, Figures 3 to 6 show the free areas, risk areas, and critical flooding points identified by municipal staff.

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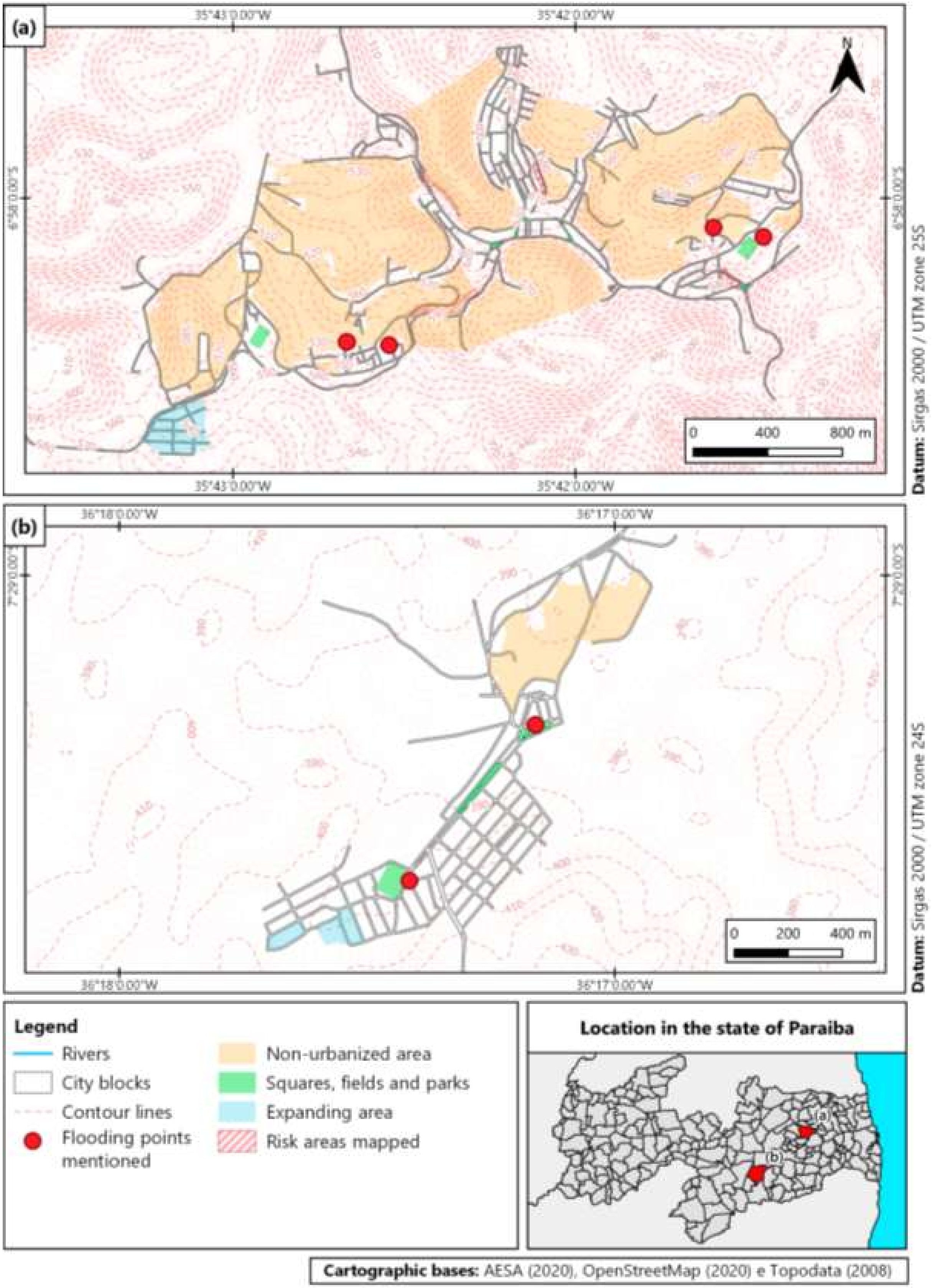

Figure 3 – Free areas, risk areas, and critical points reported by respondents in the municipalities of (a) Areia/PB and (b) Cabaceiras/PB. Source: Authors (2025).

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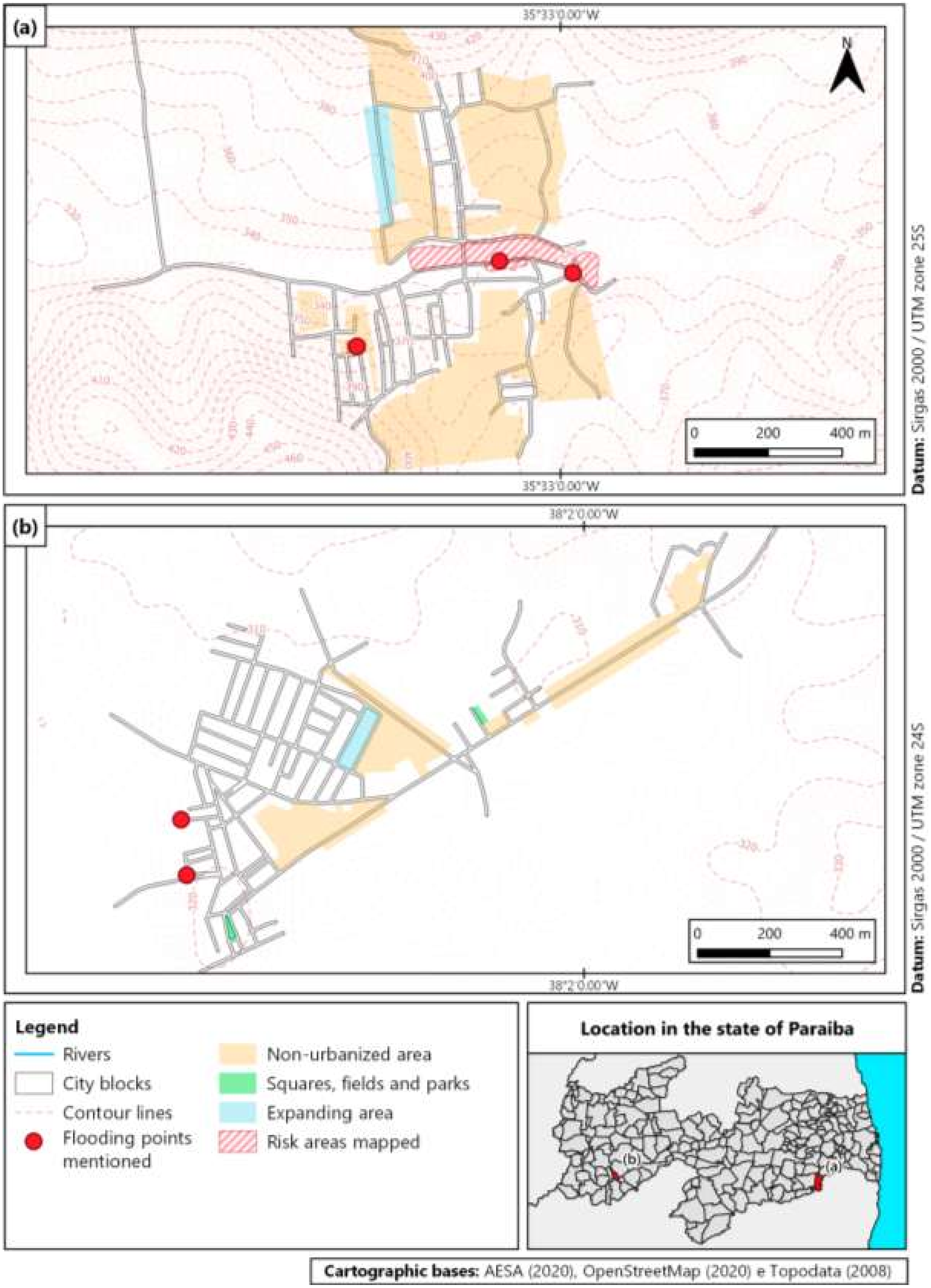

Figure 4 – Free areas, risk areas, and critical points reported by respondents in the municipalities of (a) Natuba/PB and (b) Nova Olinda/PB. Source: Authors (2025).

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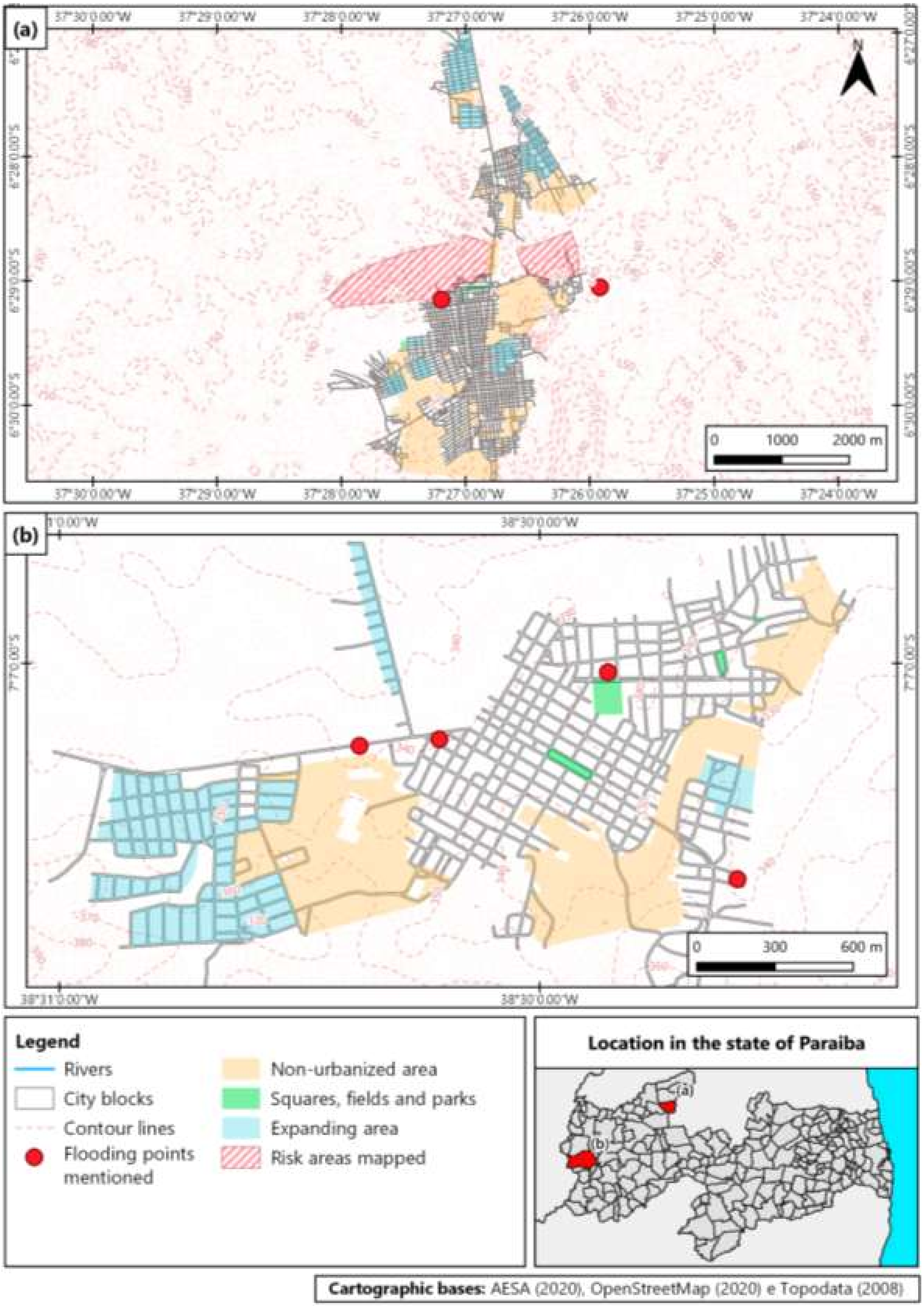

Figure 5 – Free areas, risk areas, and critical points reported by respondents in the municipalities of (a) São Bento/PB and (b) São José de Piranhas/PB. Source: Authors (2025).

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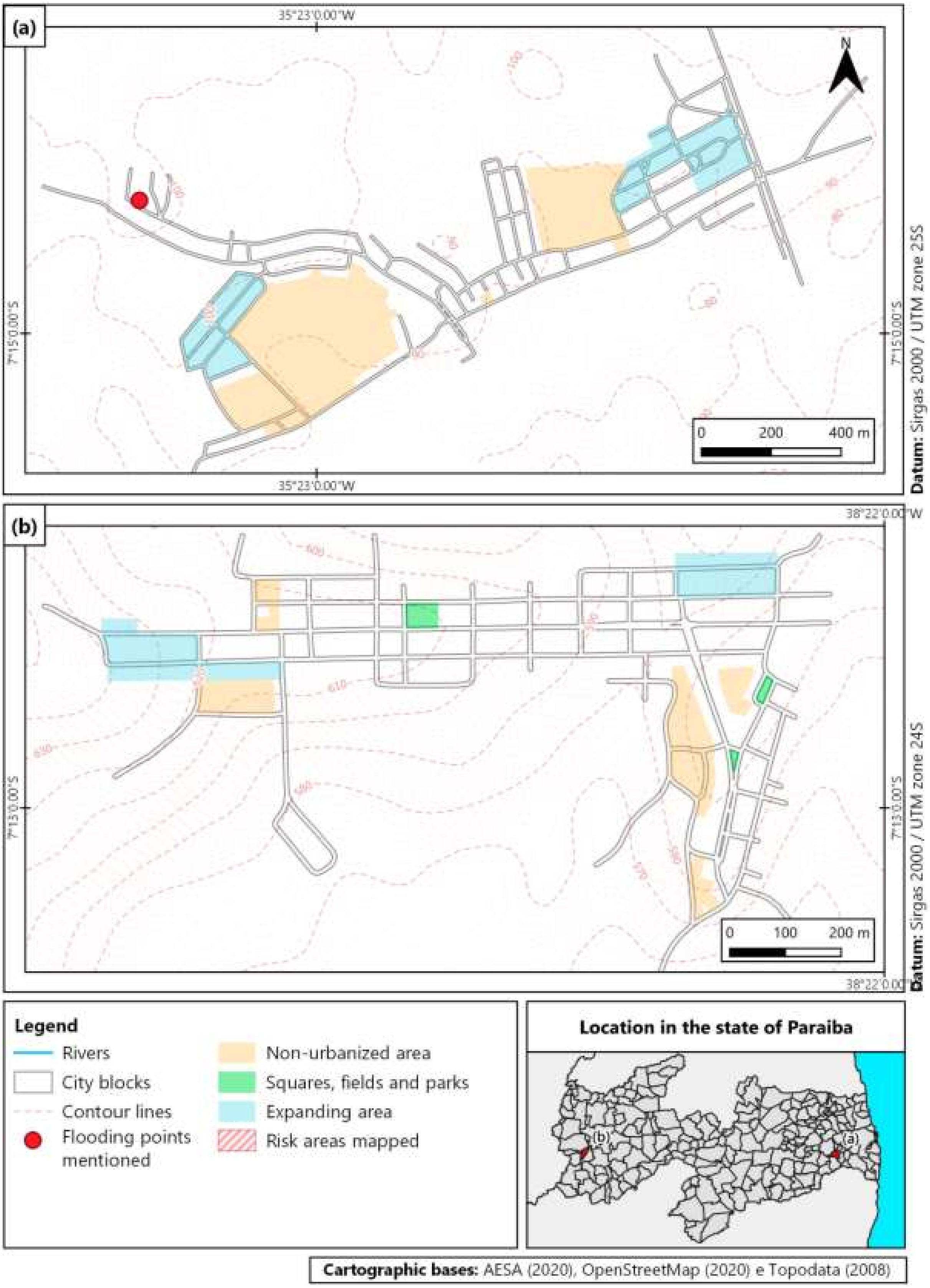

Figure 6 – Free areas, risk areas, and critical points reported by respondents in the municipalities of (a) São José dos Ramos/PB e (b) Serra Grande/PB. Source: Authors (2025).

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Selection of indicators

Most of the indicators used in this study were obtained from consolidated sources, such as the Brazilian Institute of Geography and Statistics (IBGE), the National Sanitation Information System (SNIS), DATASUS, and the Integrated Disaster Information System (S2ID). In addition to these, two new indicators were developed: the vertical curve compatibility indicator at road intersections and the waste collection and system maintenance indicator, adapted from those proposed by Silva, Pinheiro, and Lopes (2013). These new indicators were created with the aid of geoprocessing tools, such as Google Street View images and SENTINEL-2 satellite imagery, allowing for a more precise and contextualized analysis of the reality of the studied municipalities. The indicators selected to compose the index were grouped into seven categories that influence the quality and performance of the evaluated system. These indicators, their formulations, and units of measurement are detailed in Table 3.

Table 3 – Indicator formulations.

Indicator		Formulation	Unit
Existing system	Coverage of public streets with underground network	$\frac{\text{Public streets with underground channels}}{\text{Total street length}}$	%
	Pavement and curb coverage rate	$\frac{\text{Street faces with curb}}{\text{Total street faces length}}$	%
	Street faces with presence of storm drains	$\frac{\text{Street faces with storm drains}}{\text{Total street faces length}}$	%
	Vertical curve compatibility at road intersections	Existence of vertical curve compatibility at intersections	Yes/No
	Natural drainage beds channeled in the urban area	$\frac{\text{Length of artificial channels}}{\text{Length of natural beds in urban area}}$	%
System maintenance	Maintenance of the drainage system in the reference year	Occurrence of system maintenance in the reference year	Yes/No
	Coverage of direct household collection service	$\frac{\text{Area served by collection service}}{\text{Total urban area}}$	%
Urbanization	Street paving	$\frac{\text{Length of paved streets}}{\text{Total street length}}$	%
	Urban tree coverage	$\frac{\text{Arborized area}}{\text{Number of inhabitants}}$	m^2/inh.
	Impermeabilization	$\frac{\text{Impermeabilized area}}{\text{Total urban area}}$	%
Health	Hospitalization index for diseases related to inadequate stormwater drainage in the last 10 years	$\frac{\text{Hospitalizations for related diseases in the last 10 years}}{\text{Total population}}$	hospitalizations/100 thousand inh.
Economic-financial	Per capita expenditure on urban drainage and stormwater management services	Per capita amount spent on drainage and stormwater management services	R$/ inh.year

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Table 3 – Indicator formulations (continued).

Indicator		Formulation	Unit
Risk management And state conditions	Average annual precipitation over the last 20 years	Average annual precipitation of the historical series	mm
	Occurrence of floods and flash floods in the last 20 years	Number of extreme events in the last 20 years	Occurrences
	Population impacted by hydrological events in the last 5 years	Population impacted by extreme events in the last 5 years	Inh.
	Urban area officially considered at risk	$\frac{\text{Risk areas mapped by CPRM}}{\text{Total urban area}}$	%
	Share of households in risk situations	$\frac{\text{Households in risk areas}}{\text{Total households in the urban area}}$	%
	Access roads compromised during rainy periods	$\frac{\text{Compromised access roads}}{\text{Total access roads}}$	%
	Density of critical points in the urban area reported by locals	$\frac{\text{Critical points reported in interviews}}{\text{Total urban area}}$	Points/km^2
	Existence of risk management institutions	Existence of risk management institutions	Yes/No
	Existence of alert systems	Existence of alert systems	Yes/No
Institutional and legislative	Existence of a master plan or urban drainage master plan	Existence of master plan	Yes/No

Source: Authors (2025).

Definition of nominal classification

To create the performance classification categories, a nominal scale was assigned associated with index intervals. The delimitation of the intervals was based on previous studies in the field of environmental sanitation (Ogata, 2014; Lopes et al., 2016; Novaes, 2017). The five established nominal classifications were: excellent, good, average, poor, and very poor. The index intervals for each nominal classification are shown in Table 4.

Table 4 – Performance classification categories.

Nominal classification	Assigned USSPI intervals
Excellent	0.76 – 1.00
Good	0.61 – 0.75
Average	0.46 – 0.60
Poor	0.31 – 0.45
Very Poor	0 – 0.30

Source: Authors (2025).

Application of the Analytic Hierarchy Process (AHP) method

The hierarchical analysis method, known as the Analytic Hierarchy Process (AHP), was developed in 1970 by Professor Thomas L. Saaty from the University of Pennsylvania. It is one of the first models created to support decision-making in environments with multiple criteria, both quantitative and qualitative (Pereira; Brandalise;

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Mello, 2016). This approach allows for solving complex and dynamic problems, as the decision system is structured hierarchically, organizing the elements of the process that share similar characteristics. This facilitates the rapid identification of these aspects, especially when the goal is to choose among alternatives based on multiple attributes (Tona et al., 2017).

The hierarchical structure of the developed model is shown in Figure 7. For the definition of weights, a questionnaire was applied (Annex A). A non-probabilistic intentional convenience sampling was adopted, in which 19 specialists in urban drainage and stormwater management were selected from various educational institutions in Paraíba. During the process, care was taken to avoid conflicts of interest, ensuring the impartiality and reliability of the obtained responses. This approach allowed for a thorough and well-founded evaluation, essential for validating the proposed model.

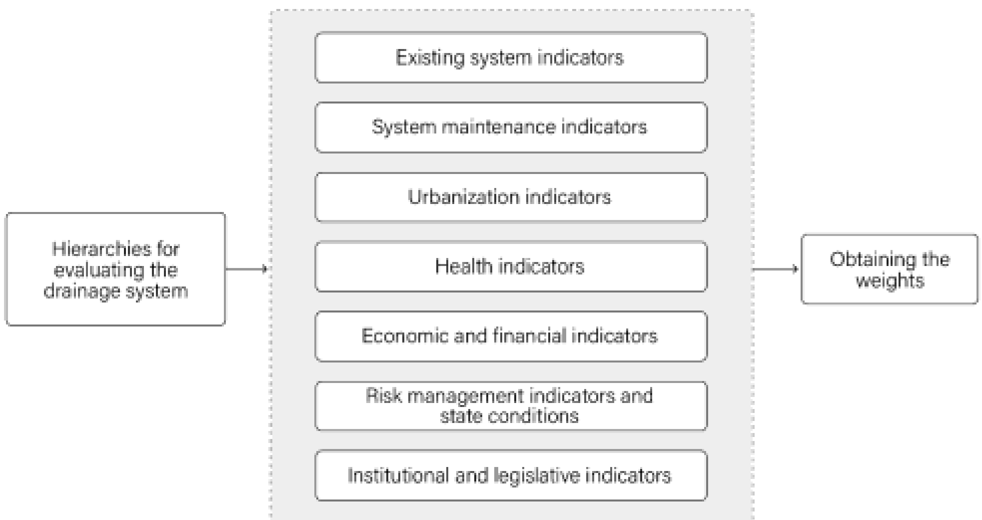

Figure 7 – Location of the municipalities selected as case studies in Paraíba. Source: Authors (2025).

The assignment of importance intensities was carried out through the application of questionnaires to the specialists, using a scale from 1 to 9 (Saaty, 1990). Based on the responses, the weights of the criterion groups in relation to the overall objective, as well as the relative weights of the criteria within each group, were obtained. This methodology allowed for a structured and consistent evaluation, essential for informed decision-making.

The judgment matrices, used to determine the weights associated with the indicators, were filled out based on the experience of specialists in the study area. However, these judgments may present logical inconsistencies, especially in higher-order matrices. To assess the consistency of the responses, the consistency

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index proposed by Saaty (1990) was used, represented by Equation 1, where $\lambda máx$ corresponds to the maximum eigenvalue and N is the order of the matrix.

$$\mathrm{CI} = \frac{|\lambda \mathrm{máx} - \mathrm{N}|}{\mathrm{N} - 1} \qquad \text{Eq. (1)}$$

To reduce the subjectivity and inherent inconsistencies of the method, Saaty (1990) proposed the Consistency Ratio (CR), represented by Equation 2. In this formula, CI orresponds to the consistency index of the matrix, and RI is the random consistency index, which varies according to the order of the matrix. The Consistency Ratio allows for the assessment of the reliability of the judgments made by the specialists, ensuring that the responses fall within an acceptable consistency limit, generally defined as CR ≤ 0.10.

$$\mathrm{CR} = \frac{CI}{IR} \qquad \text{Eq. (2)}$$

If this limit is not met, the specialist should be asked to review their judgments, adjusting the responses to ensure the necessary logical consistency. This step is crucial to guarantee the reliability and validity of the weights assigned to the criteria, maintaining the robustness of the decision-making process.

The indicators were aggregated using the arithmetic weighted mean method, where each normalized indicator is multiplied by its respective weight, followed by the summation of all products. The indicators need to be normalized as a way to transform all variables into dimensionless numbers of the same order of magnitude, allowing for comparison between variables and ensuring that the index ranges from 0 to 1. Normalization was carried out using the continuous improvement method. For a more detailed explanation of the method, see Ogata (2014) and Lacerda (2021).

Based on the aggregated indicators and obtained weights, Equation 3 was proposed, representing the Urban Stormwater Service Performance Index for small municipalities in the state of Paraíba (USSPI). The USSPI values range from 0 to 1, with 0 corresponding to the "very poor" classification and 1 to the "excellent" classification, as shown in Table 4.

$$\mathrm{USSPI} = \sum_{i=0}^{N} w_i \cdot I_i \qquad \text{Eq. (3)}$$

Where: USSPI corresponds to the Urban Stormwater Service Performance Index for small municipalities in the state of Paraíba; w_i is the weight assigned to each indicator; I_i is each selected indicator; and N is the total number of indicators used.

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Application of the Urban Stormwater Service Performance Index and Robustness Analysis

The results derived from the multi-criteria models are highly influenced by the weights assigned to their parameters. The robustness of the model was evaluated for two different objectives: obtaining a ranking of municipalities with the best stormwater drainage service and their classification.

To assess the performance of the municipal systems, the minimum and maximum values that the weights of each indicator could reach without causing a change greater than 0.07 in its absolute index were analyzed. This criterion was defined so that a municipality obtaining an index equal to the central value of any nominal class would not change its classification after the addition or subtraction of the number. Considering the comparison among several municipalities, the minimum and maximum values were determined without altering the ranking of the municipalities. The calculation of the limits was performed using Microsoft Excel software.

Finally, the coherence of the developed index was evaluated in relation to the reality of the studied cities, taking into account their geographical, demographic, and urban characteristics, and comparing it with the situation of the drainage system in the selected municipalities. The analysis was based on information from meetings with municipal technicians, regional newspaper data, risk area reports, and academic studies, which allowed for the assessment of water bodies, urban expansion areas, and flood risk zones, as well as aspects such as soil type and drainage system coverage, ensuring a comprehensive and representative evaluation of the reality of each municipality.

III. RESULTS AND DISCUSSION

Selection of Indicators

The indicators proposed in the methodology were analyzed in terms of relevance, redundancy with other indicators, applicability to small municipalities, and reliability of the values obtained. This methodology ensures that the developed index is representative, adapted to local realities, and based on accurate and reliable data, promoting a robust and contextualized evaluation.

After consulting specialists through a questionnaire, three indicators had an average score below two, classifying them as of low relevance and therefore excluded from the study. These were: per capita expenditure on drainage services; average annual precipitation; and access roads to the city compromised. This result can be explained by the low influence of these indicators on the urban drainage system or by the interference of other factors in the interpretation of their values.

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Redundant indicators were analyzed in terms of the relevance assigned by the specialists. The one with the lowest weighted mean in each pair was excluded. Thus, the indicators "Street paving rate," "Urban area considered at risk," and "Rate of streets with underground stormwater network" were excluded.

The existence of alert systems was also removed from the proposed indicators due to low applicability from the perspective of small municipalities in the state of Paraíba. None of the municipalities in the state have an alert system for extreme events related to urban drainage. Existing systems are state-level and are limited to warnings about heavy rainfall events. Therefore, the contribution of this indicator to the index would be minimal, as there are no differences between municipalities.

Finally, the indicator "population impacted by hydrological events" was excluded due to the low reliability of its values. The indicators selected to compose the index are shown in Table 5.

Table 5 – Description and formulation of the indicators.

Category	Acronym	Indicator
Existing system	ISE_2	Pavement and curb coverage rate
	ISE_3	Street faces with presence of storm drains
	ISE_4	Compatibility of vertical curves at intersections
	ISE_5	Natural drainage sections channeled in the urban area
System maintenance	IMS_1	Maintenance of the drainage system in the reference year
	IMS_2	Coverage of direct household waste collection
Urbanization	IUR_2	Urban tree coverage
	IUR_3	Soil impermeabilization
Health	ISA_1	Hospitalizations related to inadequate drainage (per 100,000 inhabitants)
Risk management and state conditions	IGR_2	Occurrence of floods and flash floods in the last 20 years
	IGR_5	Share of households in risk situations
	IGR_7	Density of critical points in the urban area cited by locals
	IGR_8	Existence of risk management institutions
Institutional and legislative	IIL_1	Existence of specific legislation for drainage

Source: Authors (2025).

From this selection, it can be observed that the retained indicators reflect different dimensions of susceptibility to urban flooding. Structural variables, such as the pavement and curb coverage rate, street faces with the presence of storm drains, and the compatibility of vertical curves at intersections, act to reduce vulnerability by promoting efficient stormwater runoff. Periodic maintenance of the system and the proper adaptation of natural drainage beds also help decrease the occurrence of flooding. Conversely, soil impermeabilization and the density of critical points increase susceptibility by exacerbating surface runoff and the exposure of urban areas. Environmental and institutional indicators, such as urban tree coverage, the existence of risk management institutions, and specific drainage legislation, serve as mitigating factors, reflecting the municipalities' capacity for planning and responding to extreme events.

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Application of the Analytic Hierarchy Process (AHP)

The consistency ratios of the pairwise comparison matrices were calculated considering an order of N = 14 and IR = 1.57 (Saaty, 1990). The consistency ratio values for each judgment matrix are presented in Table 6.

Table 6 – Performance classification categories for each evaluated questionnaire.

Experts	Maximum eigenvalue	Consistency Index	Consistency Ratio	Final situation
1	15.958	0.151	0.096	Consistent
2	15.990	0.153	0.098	Consistent
3	15.678	0.129	0.082	Consistent
4	16.785	0.214	0.136	Inconsistent
5	15.979	0.152	0.097	Consistent
6	15.875	0.144	0.092	Consistent
7	18.151	0.319	0.203	Inconsistent
8	15.355	0.104	0.066	Consistent
9	15.968	0.151	0.096	Consistent
10	15.672	0.129	0.082	Consistent
11	17.464	0.266	0.170	Inconsistent
12	15.823	0.140	0.089	Consistent

Fonte: Autores (2025).

As recommended by Saaty (1990), matrices with a Consistency Ratio (CR) ≤ 0.10 are considered consistent and, therefore, valid for use in the process. In the case of inconsistent matrices, which totaled three out of the twelve analyzed (25.0%), the ideal procedure would be to review the judgments with the experts who completed them in order to reduce inconsistencies. However, considering that the majority of matrices (nine out of twelve) showed acceptable consistency and that the identified inconsistencies do not significantly compromise the overall robustness of the model, it was decided to proceed with the analysis without excluding responses or performing additional revisions.

To determine the final weight of each indicator, a statistical treatment of the data was conducted to identify and eliminate outliers (values outside 1.5 times the interquartile range of the sample). The descriptive statistics of the weights, after outlier removal, are detailed in Table 7. Since the elimination of these values altered the distribution of the data, it was necessary to normalize the indicator means, ensuring that the final sum of the weights equaled 1. This procedure ensured the consistency and reliability of the weights assigned to each indicator.

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Table 7 – Descriptive statistics of the weights of each indicator, including: minimum value, maximum value, mean, and standard deviation.

Acronyms	Indicators	Descriptive statistics				Final weight
		Minimum value	Maximum value	Mean	Standard deviation	
ISE_2	Pavement and curb coverage rate	0.0136	0.1153	0.0472	0.0372	0.0542
ISE_3	Street faces with stormwater drains	0.0102	0.1389	0.0627	0.0412	0.0720
ISE_4	Gutter alignment at intersections	0.02	0.0984	0.0465	0.0284	0.0534
ISE_5	Rate of channeled natural drainage sections	0.0094	0.1056	0.0448	0.0371	0.0515
IMS_1	Maintenance of drainage system in reference year	0.0264	0.0509	0.0381	0.0085	0.0438
IMS_2	Coverage of direct household waste collection	0.0234	0.1185	0.0555	0.0365	0.0638
IUR_2	Urban tree coverage rate	0.0118	0.0893	0.0459	0.0303	0.0527
IUR_3	Soil impermeabilization rate	0.037	0.1673	0.0973	0.0425	0.1118
ISA_1	Hospitalizations related to inadequate drainage (per 100,000 inhabitants)	0.0182	0.1158	0.0508	0.0365	0.0583
IGR_2	Occurrence of floods and flash floods in the last 20 years	0.0261	0.1694	0.087	0.0522	0.1000
IGR_5	Share of households in risk situations	0.0173	0.1797	0.0846	0.0475	0.0972
IGR_7	Density of critical flood points in urban area	0.0309	0.1375	0.082	0.0341	0.0943
IGR_8	Existence of risk management institutions	0.0156	0.0932	0.0582	0.0303	0.0668
IIL_1	Existence of specific drainage legislation	0.0159	0.1691	0.0696	0.0538	0.0800
Sum		-	-	0.8701	-	1.0000

Source: Authors (2025).

From Table 7, it can be observed that the highest weights were assigned to the indicators of the proportion of households in risk situations and the soil impermeabilization rate. The studies by Basal et al. (2022) and Swain et al. (2020) also assign high weights to indicators related to population vulnerability to risk, since community exposure to extreme hydrological events has direct implications for public health, safety, and social well-being. According to Gao et al. (2022), soil impermeabilization is a critical factor in urban areas, as it increases flood peaks and overloads drainage systems.

According to the specialists' assessment, factors such as the history of extreme events, the absence or disregard of land use and occupation laws, direct anthropogenic actions causing soil impermeabilization, and inadequate infrastructure are the main contributors to the performance of urban stormwater drainage and management systems, representing approximately 51.52% of the index. On the other hand, the indicators related to system maintenance and urban tree cover received the lowest final weights, reflecting a lower perceived influence on the overall system performance.

The results demonstrate a stronger alignment of the specialists with new urban drainage approaches, consistent with sustainable practices. Indicators based on the preservation of the pre-urbanized landscape, such

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as soil impermeabilization rate and preservation of channeled natural watercourses, represent 16.52% of the index. In contrast, indicators related to conventional drainage systems, which focus on traditional solutions, account for 12.62%. This difference reflects a growing trend toward valuing strategies that prioritize environmental integration and reduce the impacts caused by urbanization (Kourtis; Tsihrintzis, 2021).

The final weights assigned to each indicator category are detailed in Table 8. It is important to note that the economic-financial category was excluded during the validation stage due to the low relevance of the selected indicator and the difficulty in obtaining reliable and specific economic data for urban drainage systems. This limitation reflects the challenges faced, especially by small municipalities, in collecting accurate and disaggregated financial information due to restricted data availability, scarcity of trained personnel, and workload overload (Moretti et al., 2021).

Table 8 – Final weights by indicator category of the developed index.

Category	Final weight
Existing system	0.2311
System maintenance	0.1076
Urbanization	0.1645
Health	0.0583
Risk management and state conditions	0.3583
Institutional and legislative	0.0800

Source: Authors (2025).

Thus, the equation for the Urban Stormwater Service Performance Index (USSPI), applicable to small municipalities in the state of Paraíba, was obtained by aggregating the products of the final weights assigned and their respective indicators. The index is represented by Equation 4, which synthesizes the contribution of each indicator to the overall assessment of the drainage system's performance. This approach allows for a quantitative and structured analysis, facilitating the identification of priority areas for interventions and improvements.

$$\begin{aligned}\text{USSPI} = 0{,}0542 \cdot ISE_2 + 0{,}0720 \cdot ISE_3 + 0{,}0534 \cdot ISE_4 + 0{,}0515 \cdot ISE_5 + 0{,}0438 \cdot IMS_1 + 0{,}0638 \\ \cdot IMS_2 + 0{,}0527 \cdot IUR_2 + 0{,}1118 \cdot IUR_3 + 0{,}0583 \cdot ISA_1 + 0{,}1000 \cdot IGR_2 + 0{,}0972 \\ \cdot IGR_5 + 0{,}0943 \cdot IGR_7 + 0{,}0668 \cdot IGR_8 + 0{,}0800 \cdot IIL_1\end{aligned} \quad \text{Eq. (4)}$$

Application of the Urban Stormwater Service Performance Index

Table 9 presents the values obtained for the selected indicators in each of the case studies. Secondary data, which account for 65.41% of the index, were collected from consolidated databases and are fundamental for analyzing the situation of the municipalities. Additionally, five specific indicators were developed,

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representing 34.59% of the index, complementing the assessment with information adapted to local realities. This combination of secondary data and created indicators provides a more comprehensive and precise analysis of the performance of drainage and stormwater management systems in the municipalities studied, allowing a detailed and contextualized view of the challenges and potentials of each locality.

The alignment of curbs at intersections is present in almost all municipalities studied, helping to prevent the accumulation of rainwater on public roads. Regarding the drainage channels that traverse urban areas, most municipalities have natural channels, often with banks occupied by buildings, which can compromise efficient water flow. Only Nova Olinda and Serra Grande stand out for having all channels canalized, following natural watercourses and preserving the natural flow of rainwater. This difference reflects variations in management practices and infrastructure among the analyzed municipalities.

Urban tree coverage rates vary significantly among the municipalities studied. Those located in the eastern regions of the Borborema Plateau, such as Areia and Cabaceiras, show better performance in this indicator, reflecting greater vegetation coverage. On the other hand, municipalities closer to the coast and the state's hinterland record lower tree coverage rates.

The rate of soil impermeabilization in urban areas also shows considerable variation. The municipality of Areia stands out with extremely low values, while Nova Olinda, Serra Grande, and São José dos Ramos record higher rates due to greater soil exposure and intensified urban activities.

These differences highlight the geographic and socioeconomic particularities of each locality, directly impacting the performance of urban drainage and stormwater management systems. Factors such as geographic location, climate, population density, and urbanization practices influence the response capacity of these systems, emphasizing the need for tailored approaches to address the specific challenges of each municipality (Baum; Goldenfum, 2021), as developed in this study. This contextualization is essential for planning effective and sustainable interventions.

Indicators related to the existing system show a predominance of surface devices, such as curbs and gutters, which aid in stormwater drainage. These devices are present in more than 80% of the municipalities analyzed, with the exception of São José de Piranhas, which shows lower coverage. On the other hand, deep drainage devices, such as storm drains and underground galleries, have an average coverage of 10%, ranging from 0% to 30% across the studied municipalities. This disparity reflects the predominance of surface solutions in most localities, while more complex and deeper systems are less frequent, indicating possible gaps in drainage infrastructure.

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Table 9 – Values obtained for each of the indicators of the developed index.

Indicators	Municipality							
	Areia	Cabaceiras	Natuba	Nova Olinda	São Bento	São José de Piranhas	São José dos Ramos	Serra Grande
Streets with Pavement and Curbs (%)	88.90	83.33	80.00	80.00	89.29	55.00	80.00	47.06
Streets with storm drains (%)	16.72	1.42	18.80	4.56	12.56	0.50	31.86	6.15
Curb alignment at intersections	Não	Sim	Não	Sim	Sim	Não	Sim	Sim
Rate of canalized natural channels (%)	11.70	13.79	14.76	100.00	17.72	2.18	51.93	100
Was the system maintained?	Não	Não	Sim	Não	Não	Não	Sim	Sim
Coverage of waste collection service (%)	100.0	100.00	100.00	99.91	100.00	100.00	100.00	100
Urban tree coverage (m²/inhabitant)	71.81	53.16	1.27	12.65	29.1	12.61	5.84	58.34
Soil impermeabilization rate (%)	38.75	50.69	51.94	56.75	50.50	51.13	53.64	53.56
Hospitalizations related to inadequate drainage (per 100,000 inhabitants)	16.3	14.7	4.8	41.4	92.9	308.9	12.3	16.7
Floods and flash floods in the last 20 years (units)	2	3	3	2	2	0	4	0
Households in risk situation (%)	1.70	6.50	4.12	0.00	0.50	2.00	8.30	0.00
Density of critical flood points (units/km)	0.74	0.66	2.52	1.42	0.19	0.76	0.63	0
Existence of risk management institutions	Yes	Yes	No	Yes	No	Yes	No	No
Existence of specific legislation for drainage	No	Yes	No	No	No	No	No	No

Source: IBGE (2010), SNIS (2019), S2ID (2020), and DATASUS (2020).

In 2019, maintenance of the drainage system was carried out in only three of the municipalities analyzed, highlighting that the majority do not perform frequent maintenance of drainage devices. On the other hand, the waste collection service is present in all municipalities. However, technical visits revealed that it is still common to find accumulated waste on the streets, which compromises the performance of the drainage system by obstructing curbs, storm drains, and other devices, increasing the risks of flooding (Rodrigues et al., 2022).

The survey of hospitalizations due to diseases related to inadequate drainage over the past ten years revealed high frequencies in São Bento and São José de Piranhas, indicating lower efficiency of the drainage systems in these municipalities. In the other municipalities, rates are lower, ranging from 4.8 to 16.7 hospitalizations per 100,000 inhabitants. Additionally, the number of floods and flash floods recorded over the last 20 years is relatively consistent among the municipalities, suggesting that these events are common in the region, regardless of differences in drainage system efficiency. These data reinforce the need for investments in infrastructure and risk management to reduce the negative impacts associated with inadequate drainage.

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Through the indicator that evaluates the proportion of households at risk, it was observed that the presence of streams, creeks, reservoirs, and rivers near urban areas is directly related to a higher number of buildings and people at risk. The municipality of São José de Piranhas, which is surrounded by water bodies, shows a high percentage of households at risk (37.72%), reflecting the vulnerability of the local population. In contrast, Nova Olinda and Serra Grande stand out with excellent performance in this indicator (0.00%), indicating the absence of households in risk areas, possibly due to more efficient urban planning and location farther from water bodies. This analysis underscores the importance of risk management strategies and territorial planning to reduce population exposure to extreme events.

In the other municipalities, up to 10% of households are at risk. This condition is strongly associated with the lack of risk management institutions and the absence of planning through specific legislation for stormwater drainage and management. Only the municipality of Cabaceiras has a Master Plan that includes guidelines for the stormwater drainage area. Additionally, half of the municipalities have a Municipal Civil Defense, which is still insufficient to ensure efficient risk management and adequate population protection. These data highlight the urgent need for public policies and investments in urban planning and risk management to reduce community vulnerability to extreme events.

Figure 8 presents the final index values for each municipality, positioning them on the classification scale defined in Table 10. Figure 9 shows the contribution of each indicator in each of the selected municipalities, as well as the maximum possible contribution based on the weight of each criterion. This approach allows a clear and immediate visualization of each locality's performance, facilitating the identification of municipalities that require priority interventions and those that serve as examples of good practices.

The USSPI values obtained for the selected municipalities ranged from 0.44 to 0.70. Most municipalities analyzed were classified in the medium category. Serra Grande stood out with the highest performance index (0.70), close to the limit between the good and excellent classes. On the other hand, Natuba showed the worst performance (0.44), near the limit between the poor and medium classes. This situation highlights the need for investments and improvements in planning and infrastructure to raise system performance and reduce the vulnerability of local populations to extreme events.

The low performance observed in Natuba is predominantly due to the high occurrence of extreme events in recent years, combined with a significant number of critical flooding points identified by local technicians. This context is compounded by the absence of a structured risk management policy, evidenced by the lack of municipal institutions dedicated to this purpose. Additionally, the scarcity of green areas and the limited

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coverage of the urban drainage system reduce the runoff capacity and mitigation of rainfall impacts, negatively affecting the final index value.

Although Serra Grande presented the best performance among the analyzed municipalities, it exists in a very particular urban and physical context. With the smallest urban area in the study group and a steep terrain – having an average slope of 10.90% – the municipality has a separated drainage system consisting of only four storm drains connected directly to its outlets, located on the edges of the urban area. The absence of underground galleries reveals a simplified structure whose efficiency heavily depends on the natural terrain conditions, which favor surface runoff of stormwater. This relief helps minimize flooding, partially compensating for structural and institutional limitations, such as the absence of a municipal risk management agency and specific legislation for drainage. Thus, the municipality's good performance largely reflects local topographical advantages rather than the adoption of established planning and management practices.

The comparative analysis between Natuba and Serra Grande highlights the decisive role of the variables that make up the proposed index. Structural and physical indicators – such as the rate of pavement and curb coverage, the presence of storm drains, and the alignment of vertical curves – exert strong influence on the hydraulic performance of the systems. In Natuba, the insufficiency of these elements, combined with the high density of critical points, recurring floods, and pronounced soil impermeabilization, resulted in greater urban vulnerability. In Serra Grande, despite the low density of drainage devices and the absence of underground galleries, the steeper relief favors surface runoff, mitigating the negative impact of these deficiencies.

Among the institutional variables, the absence of specific legislation and risk management institutions affected both municipalities, revealing the fragility of local governance in urban drainage. Thus, the contrast between the two municipalities reinforces that satisfactory performance may result from structural and management factors or, in some cases, from favorable natural conditions, such as terrain, which can partially mitigate deficiencies in the drainage system.

Therefore, the results indicate that prioritizing actions aimed at improving drainage infrastructure – especially the expansion and maintenance of collection devices and the control of soil impermeabilization – must be accompanied by institutional and technical strengthening, through standardization of regulations, integration of maintenance data, and the creation of municipal risk management structures. This integrated approach aligns with the recommendations of Macedo et al. (2018), who emphasize the need to systematize urban maintenance information, and Baum and Goldenfum (2021), who advocate regulatory standardization and the establishment of minimum parameters to guide public policies and sector investments.

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Table 10 – Indicators normalized on a scale from 0 to 1.

Indicators	Municipality							
	Areia	Cabaceiras	Natuba	Nova Olinda	São Bento	São José de Piranhas	São José dos Ramos	Serra Grande
Streets with pavement and curbs (%)	0.889	0.833	0.8	0.8	0.893	0.55	0.8	0.471
Streets with storm drains (%)	0.167	0.014	0.188	0.046	0.126	0.005	0.319	0.062
Alignment of curbs at intersections	0	1	0.5	1	1	0.5	1	1
Rate of channeled natural drainage sections (%)	0.117	0.138	0.148	1	0.177	0.022	0.519	1
System maintenance performed?	0	0	1	0	0	0	1	1
Waste collection service coverage (%)	1	1	1	0.999	1	1	1	1
Urban tree cover (m²/inhabitant)	1	1	0	0	0.564	0	0	1
Soil impermeabilization rate (%)	0.917	0.651	0.624	0.517	0.656	0.642	0.586	0.588
Hospitalizations related to inadequate drainage (per 100,000 inhabitants)	0.794	0.815	0.939	0.478	0	0	0.845	0.789
Floods and flash floods in the last 20 years (units)	0.5	0.25	0.25	0.5	0.5	1	0	1
Households at risk (%)	0.983	0.935	0.959	1	0.995	0.98	0.917	1
Density of critical flooding points (units/km)	0.63	0.67	0	0.29	0.905	0.62	0.685	1
Existence of risk management institutions	1	1	0	1	0	1	0	0
Existence of specific drainage legislation	0	1	0	0	0	0	0	0

Source: Authors (2025).

Although reflecting greater soil impermeabilization and human intervention in the environment, the population variation within the group of small municipalities did not significantly influence the index results. Larger municipalities, such as Areia, Natuba, São Bento, and São José de Piranhas, had similar index values to smaller municipalities, such as Nova Olinda and São José dos Ramos. Furthermore, the performance of municipalities with combined and separate drainage systems was similar, indicating that the type of system was not a determining factor for the index outcome.

Despite the progress achieved, the study presents some limitations inherent to the application of the proposed index. The main limitation concerns the availability and quality of municipal data, which are often incomplete or outdated, potentially affecting the accuracy of the results. Additionally, some of the variables used are qualitative, which may introduce a certain degree of subjectivity in the assessment. The spatial limitation of the study, restricted to a small set of municipalities, also warrants caution in generalizing the

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findings. Nevertheless, these limitations do not compromise the validity of the results but suggest directions for methodological improvements in future research.

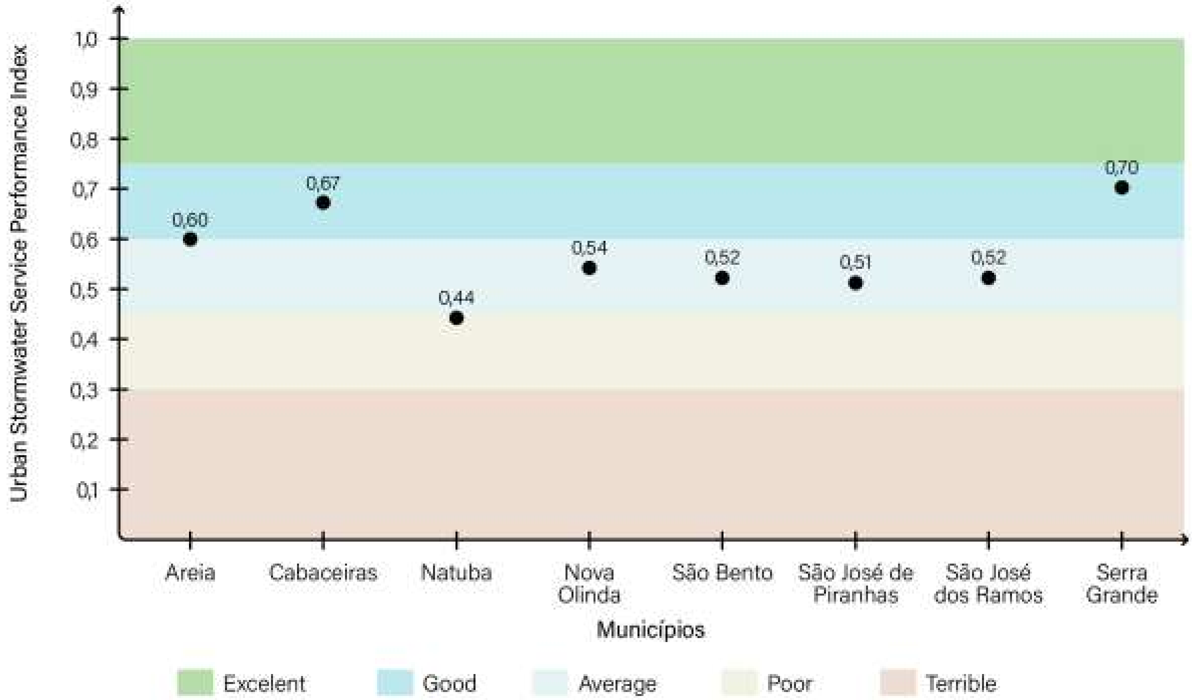

Figure 7 – USSPI results and classification of the municipalities studied. Source: Authors (2025).

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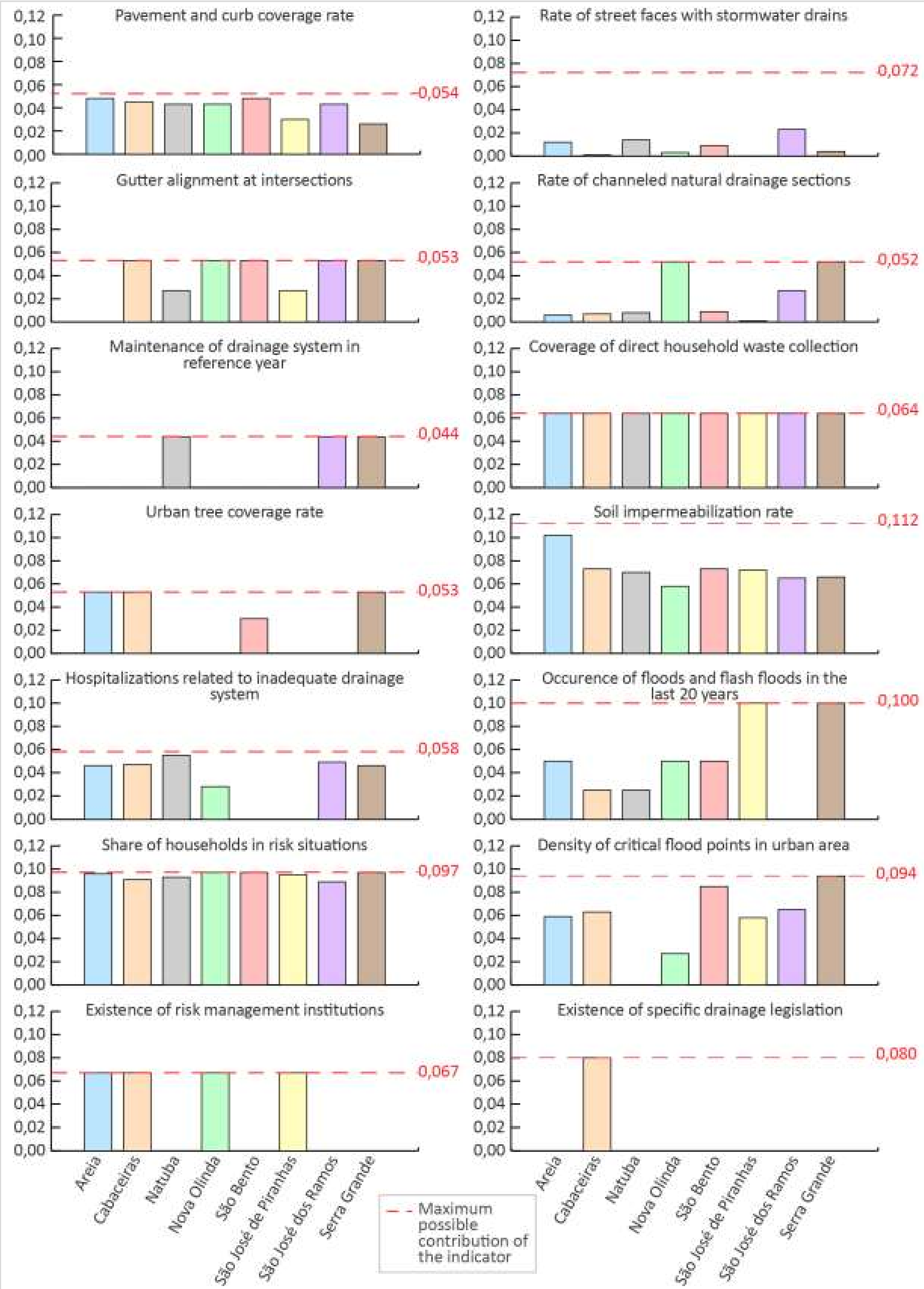

Figure 8 – Contribution of each indicator to the index for the selected municipalities. Source: Authors (2025).

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Robustness analysis of the index

Regarding the robustness analysis, the lower and upper limits within which changes in the indicator weights can occur without compromising the nominal classification or the ranking of municipalities are listed in Table 11. The larger the interval between the limits, the greater the robustness of the model for that objective. It can be observed that the stability intervals for the nominal classification of municipalities are considerably larger, indicating a higher robustness of the method for this purpose. On average, indicators can vary between 0.00 and 0.20 while still maintaining a constant classification. On the other hand, indicators with smaller stability intervals, such as system maintenance (0.00–0.14) and the existence of risk management institutions (0.00–0.16), proved to be more sensitive to variations in weights. This behavior suggests that changes in their relative importance significantly impact the final result, highlighting the strong influence of operational and institutional conditions on the performance of drainage systems.

Outside the intervals presented for each indicator, municipalities can change classification more than three times.

Table 11 – Lower and upper limits of the stability interval.

Indicators	Classification		Ranking	
	Lower limit	Upper limit	Lower limit	Upper limit
Streets with pavement and curbs	0.00	0.29	0.05	0.09
Streets with catch basins	0.00	0.17	0.06	0.13
Compatibility of gutters at intersections	0.00	0.16	0.05	0.10
Rate of channeled natural drainage sections	0.00	0.17	0.05	0.11
System maintenance performed?	0.00	0.14	0.05	0.06
Coverage of waste collection service	0.00	0.18	0.00	0.95
Urban tree coverage	0.00	0.17	0.05	0.05
Soil impermeabilization rate	0.00	0.30	0.00	0.15
Hospitalizations related to inadequate drainage	0.00	0.18	0.06	0.10
Floods and flash floods in the last 20 years	0.00	0.22	0.07	0.10
Households in risk areas	0.00	0.21	0.00	0.13
Density of flooding critical points	0.00	0.23	0.08	0.10
Existence of risk management institutions	0.00	0.16	0.05	0.07
Existence of specific drainage legislation	0.00	0.18	0.02	0.10

Source: Authors (2025).

For comparing the drainage systems of municipalities, the model proved less robust. The calculated values indicate that, on average, weights can vary between 0.05 and 0.11 without causing changes in the final ranking of municipalities. In the case study applications, some municipalities dropped up to five positions in the ranking. Only the indicator "waste collection coverage" showed a larger interval, which is justified by the consistency of its values.

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Overall, the results demonstrate that the proposed index shows satisfactory robustness for performance classification, although caution is required when interpreting comparative rankings. For practical applications, special attention is recommended for the most sensitive indicators – particularly those related to system maintenance and institutional management – as small improvements in these aspects can lead to significant gains in overall performance.

IV. CONCLUSIONS

This study highlighted the importance of indices and indicators as fundamental tools for the evaluation of urban systems and for supporting decision-making and management, acting as elements that mitigate the heterogeneity faced by municipalities. The Urban Stormwater Service Performance Index for Small Municipalities in Paraíba (USSPI) was constructed based on variables from consolidated and reliable databases, allowing its indicators to be used as a reference for comparing and assessing the quality of the services provided. In addition, five specific indicators were developed, complementing the evaluation with information adapted to local realities. This combination of secondary data and custom indicators provides a more comprehensive and precise analysis, reflecting the particularities of each municipality and contributing to more efficient and contextualized management.

The results from the application of questionnaires to specialists revealed that risk management indicators were considered the most important, followed by the identification of the existing system and urbanization. The indicators that contributed most to the index were the share of households in risk situations and the soil impermeabilization rate. Furthermore, a tendency was observed among the specialists to value sustainable approaches over conventional solutions.

A detailed analysis of the index composition for the case studies showed that positive and negative aspects vary according to the reality of each municipality. In most cases, the main problems are related to inadequate drainage infrastructure and deficiencies in risk management. The lack of planning and the absence of specific legislation for stormwater drainage were also factors that significantly influenced the results.

It should be emphasized that for the application of the USSPI in other contexts, the periodicity of data is essential. The methodology used and the information obtained can contribute to more efficient management of urban drainage services, guiding public policies and investments that reduce the damage caused by extreme events and decrease the population's vulnerability, thus supporting the decision-making process.

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V. References

AESA. Agência Executiva de Gestão das Águas do Estado da Paraíba. Shapefiles. 2020. Disponível em: <http://geoserver.aesa.pb.gov.br/geoprocessamento/geoportal/shapes.html>. Acesso em: 29 ago. 2024.

AKAISHI, A. G. Desafios do planejamento urbano-habitacional em pequenos municípios brasileiros. Risco: Revista de Pesquisa em Arquitetura e Urbanismo, v. 14, p. 41-50. 2012. https://doi.org/10.11606/issn.1984-4506.v0i14p41-50

ARAÚJO, D. C. Metodologia para apoio à decisão na gestão das águas pluviais urbanas combinando métodos multicriterial e multidecisor. Tese (Doutorado em Engenharia Civil), Universidade Federal de Pernambuco, Recife, 2016. Recife, 2016. Disponível em: <https://repositorio.ufpe.br/bitstream/123456789/18668/1/Tese_Danniel_Araujo_Vers%C3%A3o_Final_CORRIGIDA_19_12.pdf>. Acesso em: 23 set. 2025.

BANSAL, N.; MUKHERJEE, M.; GAIROLA, A. Evaluating urban flood hazard index (UFHI) of Dehradun city using GIS and multi-criteria decision analysis. Modeling Earth Systems and Environment, v. 8, p. 4051-4064, 2022. https://doi.org/10.1007/s40808-021-01348-5.

BAUM, C. A.; GOLDENFUM, J. A. Indicadores e índices para o gerenciamento de águas pluviais urbanas no Brasil: situação atual e oportunidades de evolução. Revista de Gestão de Água da América Latina, v. 18, n. 21, p. 1-16, 2021. https://doi.org/10.21168/rega.v18e21.

EMBRAPA. Empresa Brasileira de Pesquisa Agropecuária. Mapeamento de áreas urbanas. 2015. Disponível em: <http://geoinfo.cnpm.embrapa.br/layers/geonode%3Aareas_urbanas_br_15>. Acesso em: 29 ago. 2024.

FERREIRA, Y. B. C. Proposição de um Índice de Vulnerabilidade Humana à Insuficiência de Saneamento Básico em municípios de pequeno porte: a experiência do estado da Paraíba. Dissertação (Mestrado em Engenharia Civil e Ambiental), Universidade Federal de Campina Grande, Campina Grande-PB, 2020.

GAO, M.; WANG, Z.; YANG, H. Review of Urban Flood Resilience: Insights from Scientometric and Systematic Analysis. Environmental Research and Public Health, v. 19, n. 14, 2022. https://doi.org/10.3390/ijerph19148837.

IBGE. Instituto Brasileiro de Geografia e Estatística. Divisão Regional do Brasil em Regiões Geográficas Imediatas e Regiões Geográficas Intermediárias. 2017. Disponível em: <https://www.ibge.gov.br/apps/regioes_geograficas/>. Acesso em: 29 ago. 2024.

IBGE. Instituto Brasileiro de Geografia e Estatística. Geociências: Informações ambientais. 2019. Disponível em: <https://www.ibge.gov.br/geociencias/downloads-geociencias.html>. Acesso em: 29 ago. 2024.

RA'EGA
O ESPAÇO GEOGRÁFICO EM ANÁLISE
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ISSN eletrônico 2177-2738
RA'EGA, Curitiba, PR, V.64, n.1, p. 3 – 41, 12/2025
http://dx.doi.org/10.5380/raega.v64i1.102000

IBGE. Instituto Brasileiro de Geografia e Estatística. Resultados do Censo Demográfico. 2010. Disponível em: <https://censo2010.ibge.gov.br/resultados.html>. Acesso em: 29 ago. 2024.

INPE. Instituto Nacional de Pesquisas Espaciais. Topodata. 2008. Disponível em: <http://www.dsr.inpe.br/topodata/>. Acesso em: 29 ago. 2024.

KOURTIS, T. M.; TSIHRINTZIS, V. A. Adaptation of urban drainage networks to climate change: A review. Science of The Total Environment, v. 771, 2021. https://doi.org/10.1016/j.scitotenv.2021.145431.

KURIQI, A.; HYSA, A. Multidimensional Aspects of Floods: Nature-Based Mitigation Measures from Basin to River Reach Scale. In: FERREIRA, C. S. S.; KALANTARI, Z.; HARTMANN, T.; PEREIRA, P. Nature-Based Solutions for Flood Mitigation. The Handbook of Environmental Chemistry. Springer, v. 107, p. 11-33. https://doi.org/10.1007/698_2021_773.

LACERDA, M. C. Proposta de um índice para avaliação de desempenho de sistemas de drenagem de águas pluviais em cidades de pequeno porte do Estado da Paraíba. 2021. 101 p. Trabalho de Conclusão de Curso (Graduação em Engenharia Civil) - Universidade Federal de Campina Grande, Campina Grande, Paraíba.

LI, Y.; WANG, P.; LOU, Y.; CHEN, C.; SHEN, C.; HU, T. Assessing urban drainage pressure and impacts of future climate change based on shared socioeconomic pathways. Journal of Hydrology: Regional Studies, v. 53, 2024. https://doi.org/10.1016/j.ejrh.2024.101760.

LOPES, W. S.; RODRIGUES, A. C. L.; FEITOSA, P. H. C.; COURA, M. A.; OLIVEIRA, R.; BARBOSA, D. L. Determinação de um índice de desempenho do serviço de esgotamento sanitário. Estudo de caso: cidade de Campina Grande, Paraíba. 2016. Revista Brasileira de Recursos Hídricos, v. 21, n. 1, p. 1-10, 2016. http://dx.doi.org/10.21168/rbrh.v21n1.p1-10.

LUO, K.; ZHANG, X. Increasing urban flood risk in China over recent 40 years induced by LUCCL. Landscape and Urban Planning, 219, p. 104-317, 2022. https://doi.org/10.1016/j.landurbplan.2021.104317.

MACEDO, F. F.; VIEIRA, F. H.; FURIGO, R. F. R. Indicadores de manutenção do sistema de drenagem urbana em Mogi Mirim. *Boletim do Saneamento*, 30 set. 2025. Disponível em: https://boletimdosaneamento.com.br/indicadores-manutencao-sistema-de-drenagem-urbana-mogi-mirim/. Acesso em: 6 out. 2025.

MAPBIOMAS. Áreas urbanizadas no Brasil: 1985-2022. MapBiomas, 2023. Disponível em: < https://brasil.mapbiomas.org/wp-content/uploads/sites/4/2023/10/FACT_Areas-Urbanas-no-Brasil_31.10_v2.pdf>. Acesso em: 24 set. 2025.

MENDONÇA, E. C.; SOUZA, M. A. A. Uma metodologia multiobjetivo e multicritério para avaliação de desempenho de sistemas de drenagem urbana. Ineniería del Agua, v. 23, n. 2, 2019. https://doi.org/10.4995/ia.2019.10214

MORETTI, R. S.; CUNHA, P. E. V.; JUNIOR, G. T. M.; FILHO, A. F. T. Aspectos específicos do planejamento e da política pública de saneamento nos pequenos municípios. Projectare, v. 1, n. 11, p. 101-116, 2021.

NOVAES, C. A. F. O.; CORDEIRO NETTO, O. M. Desenvolvimento de metodologia para avaliação de desempenho de sistemas de drenagem urbana: aplicação ao caso da RIDE-DF e entorno. In: SIMPÓSIO BRASILEIRO DE RECURSOS HÍDRICOS, 12., 2017, Florianópolis. Anais... Florianópolis: ABRHidro, 2017.

ISSN eletrônico 2177-2738
RA'EGA, Curitiba, PR, V.64, n.1, p. 3 – 41, 12/2025
http://dx.doi.org/10.5380/raega.v64i1.102000

OGATA, I. S. Desenvolvimento do índice de pobreza hídrica para a Bacia Hidrográfica do Rio Paraíba. 2014. Dissertação (Mestrado em Engenharia Civil e Ambiental) - Universidade Federal de Campina Grande, Campina Grande, 2014.

OPENSTREETMAP. Base Cartográfica das Ruas. 2020. Disponível em: <https://www.openstreetmap.org/>. Acesso em: 29 ago. 2024.

PEREIRA, A. S.; BRANDALISE, N.; MELLO, L. C. Aplicação do método AHP na seleção de terrenos para edificações comerciais na cidade do Rio de Janeiro. Revista Eletrônica Sistema & Gestão, v. 11, n. 4, p. 410-422, 2016. https://doi.org/10.20985/1980-5160.2016.v11n4.1092

RODRIGUES, N. M.; RODRIGUES, C. E. F.; RODRIGUES, C. R. A falta de drenagem urbana nas cidades brasileiras. Research, Society and Development, v. 11, n. 6, 2022. http://dx.doi.org/10.33448/rsd-v11i6.29652.

SAATY, T. L. How to make a decision: The analytic hierarchy process. European Journal of Operational Research, v. 48, n. 1, p. 9-26, 1990. https://doi.org/10.1016/0377-2217(90)90057-I.

SÃO PAULO. Prefeitura de São Paulo. Manual de Drenagem e Manejo de águas pluviais. Volume I. São Paulo, 2012. Disponível em: <https://www.prefeitura.sp.gov.br/cidade/secretarias/upload/desenvolvimento_urbano/arquivos/manual-drenagem_v1.pdf>. Acesso em: 23 set. 2025.

SILVA, B. R.; PINHEIRO, H.; LOPES, D. D. Seleção de indicadores de sustentabilidade para avaliação do sistema de drenagem urbana. Revista Nacional de Gerenciamento de Cidades, v. 1, n. 1, p. 30-44, 2013.

STEINER, L. Trabalho de Conclusão de Curso. Avaliação do sistema de drenagem pluvial urbana com aplicação do índice de fragilidade. Estudo de caso: microbacia do Rio Criciúma, SC. Criciúma, 2011. Disponível em: <http://repositorio.unesc.net/bitstream/1/1356/1/Laura%20Steiner.pdf.pdf>. Acesso em: 23 set. 2025.

SWAIN, K. C.; SINGHA, C.; NAYAK, L. Flood susceptibility mapping through the GIS-AHP technique using the cloud. International Journal of Geo-Information, v. 9, n. 12, 2020. https://doi.org/10.3390/ijgi9120720.

TANG, Z.; WANG, P.; LI, Y.; WANGM B.; POPOVYCH, N.; HU, T. Contributions of climate change and urbanization to urban flood hazard changes in China's 293 major cities since 1980. Journal of Environmental Management, v. 353, 2024. https://doi.org/10.1016/j.jenvman.2024.120113.

TONA, R. N.; ONIAS, T.; VILELA, A.; HERNANDEZ, C. T. Aplicação do método AHP para auxílio à tomada de decisão para gestores na escolha do tipo de embalagem no desenvolvimento de novas peças do setor automobilístico. In: SIMPÓSIO DE EXCELÊNCIA EM GESTÃO E TECNOLOGIA, 14., 2017, Rio de Janeiro. Anais... Rio de Janeiro: AEDB, 2017.

VON SPERLING, T. L.; VON SPERLING, M. Proposição de um sistema de indicadores de desempenho para avaliação da qualidade dos serviços de esgotamento sanitário. Engenharia Sanitária e Ambiental, v. 18, n. 4, 2013. https://doi.org/10.1590/S1413-41522013000400003.

ZABIN, C. J.; JURGENS, L. J.; BIBLE, J. M.; PATTEN, M. V.; CHANG, A. L.; GROSHOLZ, E. D.; BOYER, K. E. Increasing the resilience of ecological restoration to extreme climatic events. Frontiers in Ecology and the Envitonment, v. 20, n. 5, 2022. https://doi.org/10.1002/fee.2471.

O ESPAÇO GEOGRÁFICO EM ANÁLISE
https://revistas.ufpr.br/raega

ISSN eletrônico 2177-2738
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Appendices

Appendix A – Questionnaire Used for Weight Definition.

CONSULTATION WITH EXPERTS FOR THE DEVELOPMENT OF A PERFORMANCE ASSESSMENT INDEX OF URBAN STORMWATER DRAINAGE SYSTEMS IN SMALL MUNICIPALITIES OF PARAÍBA

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The study aims to develop a Urban Stormwater Service Performance Index for small municipalities in the state of Paraíba (USSPI) through the weighted aggregation of indicators – both primary and secondary data – with their respective weights defined using the Analytic Hierarchy Process (AHP) method. According to the defined methodology, the selected indicators must be validated, and subsequently, the assignment of importance levels must be carried out through the application of questionnaires to a group of experts in the study area. Based on the responses, it is possible to obtain the weights of the criteria groupings with respect to the overall objective and the relative weights of the criteria within each grouping.

The questionnaire is divided into three parts: I.1) Personal information of the respondent; I.2) Validation of the indicators; I.3) Pairwise comparison of importance.

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QUESTIONNAIRE

I.1. PERSONAL INFORMATION OF THE RESPONDENT

Fill in the personal information in Table A.1. The data will be used solely for statistical analysis of the sample.

Table A.1 – Personal information of the consulted expert.

FIELD OF EXPERTISE	
ACADEMIC DEGREE	

I.2. INDICATORS VALIDATION

To validate the proposed set of indicators, Table A.2 was prepared. Fill it in with an X, classifying each indicator into only one of the following categories: very relevant, relevant, slightly relevant, and irrelevant.

Table A.2 – Validation of indicators regarding their relevance.

INDICATORS	IRRELEVANT	SLIGHTLY RELEVANT	RELEVANT	VERY RELEVANT
Rate of streets with underground stormwater network				
Rate of streets with curbs				
Rate of streets with storm drains				
Gutter alignment at intersections				
Rate of channeled natural drainage sections				
Type of system maintenance				
Coverage of waste collection service				
Rate of street paving				
Urban tree coverage rate				
Soil imperviousness rate				
Hospitalizations due to inadequate stormwater drainage				
Per capita expenditure on drainage services				
Average annual precipitation				
History of floods and flash floods				
Population affected by hydrological events				

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Urban area considered at risk				
Proportion of households in risk areas				
Access roads to the city compromised				
Density of flood-prone critical points				
Existence of risk management institutions				
Existence of alert systems				
Existence of stormwater master plan				

I.3. PAIRWISE COMPARISON OF IMPORTANCE

To obtain the relative importance among the criteria, they will be compared pair by pair by assigning importance intensities on a scale from 1 to 9 (Table A.1), as proposed by Saaty (1990). If an attribute is less important than its pair, the value should be the reciprocal of that shown in Table A.1.

Table A.1 – Scale for comparative judgments.

Importance Intensity	Definition	Explanation
1	Equal importance	Both attributes contribute equally to the objective.
3	Weak importance of one over the other	Experience and judgment slightly favor one attribute over the other.
5	Strong or essential importance	Experience and judgment strongly favor one attribute over the other.
7	Very strong or demonstrated importance	One attribute is strongly favored over the other; its predominance of importance is demonstrated in practice.
9	Absolute importance	Evidence favors one attribute over the other with the highest degree of certainty.
2, 4, 6, 8	Intermediate values between adjacent values	Used when a condition of favoring one attribute over another falls between two definitions.

Source: Adapted from Saaty (1990)

Table A.4 should be filled out according to the example below (Table A.3), always comparing the attribute in the row with the attribute in the column.

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Table A.3 – Example of how to fill out Table A.4.

	A	B	C
A	1	-	-
B	3	1	-
C	5	1/7	1

In the example above, attribute B has a weak importance over attribute A, being slightly favored. In the case of attribute C, it has strong importance over attribute A (intensity 5), but when compared to attribute B, it has an inverse value of 1/7. In this case, B is the one with very strong importance (intensity 7) over attribute C, and not the other way around.

In summary, whole numbers should be used when the row attribute has greater importance than the column attribute. Inverse values should be used when the column attribute has greater importance than the row attribute.

Table A.4 **–** Pairwise comparison of indicator importance (Part 1 of 3).

Qual a intensidade de importância do **atributo A** quando comparado ao **atributo B**? **Valores inteiros:** A tem maior importância que B. **Valores inversos:** B tem maior importância que A. / **ATRIBUTO B** / **ATRIBUTO A**	**Taxa de ruas com rede pluvial subterrânea**	**Taxa de ruas com meio-fio**	**Taxa de ruas com bocas de lobo**	**Compatibilização de sarjetas em cruzamentos**	**Taxa de leitos naturais canalizados**	**Tipo de manutenção do sistema**	**Cobertura do serviço de coleta de lixo**	**Taxa de pavimentação de ruas**	**Taxa de arborização urbana**	**Taxa de impermeabilização do solo**	**Internações por doenças relacionadas à drenagem pluvial inadequada**	**Despesa per capita com serviços de drenagem**	**Precipitação anual média**	**Histórico de alagamentos e enxurradas**	**População impactada por eventos hidrológicos**	**Área urbana considerada de risco**	**Parcela de domicílios em situação de risco**	**Vias de acesso à cidade comprometidas**	**Densidade de pontos críticos de alagamento**	**Existência de instituições de gestão de risco**	**Existência de sistemas de alerta**	**Existência de plano diretor de drenagem**
Taxa de ruas com rede pluvial subterrânea	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Taxa de ruas com meio-fio		1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Taxa de ruas com bocas de lobo			1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Compatibilização de sarjetas em cruzamentos				1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Taxa de leitos naturais canalizados					1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Tipo de manutenção do sistema						1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cobertura do serviço de coleta de lixo							1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Taxa de pavimentação de ruas								1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Taxa de arborização urbana									1	-	-	-	-	-	-	-	-	-	-	-	-	-

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Table A.4 – Pairwise comparison of indicator importance (Part 2 of 3).

Qual a intensidade de importância do **atributo A** quando comparado ao **atributo B**?

Valores inteiros: A tem maior importância que B.
Valores inversos: B tem maior importância que A.

ATRIBUTO A \ ATRIBUTO B	Taxa de ruas com rede pluvial subterrânea	Taxa de ruas com meio-fio	Taxa de ruas com bocas de lobo	Compatibilização de sarjetas em cruzamentos	Taxa de leitos naturais canalizados	Tipo de manutenção do sistema	Cobertura do serviço de coleta de lixo	Taxa de pavimentação de ruas	Taxa de arborização urbana	Taxa de impermeabilização do solo	Internações por doenças relacionadas à drenagem pluvial inadequada	Despesa per capita com serviços de drenagem	Precipitação anual média	Histórico de alagamentos e enxurradas	População impactada por eventos hidrológicos	Área urbana considerada de risco	Parcela de domicílios em situação de risco	Vias de acesso à cidade comprometidas	Densidade de pontos críticos de alagamento	Existência de instituições de gestão de risco	Existência de sistemas de alerta	Existência de plano diretor de drenagem
Taxa de impermeabilização do solo										1	-	-	-	-	-	-	-	-	-	-	-	-
Internações por doenças relacionadas à drenagem pluvial inadequada											1	-	-	-	-	-	-	-	-	-	-	-
Despesa per capita com serviços de drenagem												1	-	-	-	-	-	-	-	-	-	-
Precipitação anual média													1	-	-	-	-	-	-	-	-	-
Histórico de alagamentos e enxurradas														1	-	-	-	-	-	-	-	-
População impactada por eventos hidrológicos															1	-	-	-	-	-	-	-
Área urbana considerada de risco																1	-	-	-	-	-	-
Parcela de domicílios em situação de risco																	1	-	-	-	-	-
Vias de acesso à cidade comprometidas																		1	-	-	-	-

Table A.4 – Pairwise comparison of indicator importance (Part 3 of 3).

Qual a intensidade de importância do **atributo A** quando comparado ao **atributo B**?

Valores inteiros: A tem maior importância que B.
Valores inversos: B tem maior importância que A.

ATRIBUTO A \ ATRIBUTO B	Taxa de ruas com rede pluvial subterrânea	Taxa de ruas com meio-fio	Taxa de ruas com bocas de lobo	Compatibilização de sarjetas em cruzamentos	Taxa de leitos naturais canalizados	Tipo de manutenção do sistema	Cobertura do serviço de coleta de lixo	Taxa de pavimentação de ruas	Taxa de arborização urbana	Taxa de impermeabilização do solo	Internações por doenças relacionadas à drenagem pluvial inadequada	Despesa per capita com serviços de drenagem	Precipitação anual média	Histórico de alagamentos e enxurradas	População impactada por eventos hidrológicos	Área urbana considerada de risco	Parcela de domicílios em situação de risco	Vias de acesso à cidade comprometidas	Densidade de pontos críticos de alagamento	Existência de instituições de gestão de risco	Existência de sistemas de alerta	Existência de plano diretor de drenagem
Densidade de pontos críticos de alagamento																			1	-	-	-
Existência de instituições de gestão de risco																				1	-	-
Existência de sistemas de alerta																					1	-
Existência de plano diretor de drenagem																						1

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