Acta Scientiarum

http://periodicos.uem.br/ojs
ISSN on-line: 1807-8664
Doi: 10.4025/actascitechnol.v45i1.63176

CIVIL ENGINEERING

Performance evaluation of urban drainage systems: an analytic hierarchy process approach for the Jaracati basin in Brazil

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ABSTRACT. The efficiency of drainage systems in urban centers and especially in their peripheral regions has deserved more and more special attention since their interrelationship with social and environmental aspects is associated with the performance of drainage infrastructures. Integrated urban water management is a major factor in the effectiveness of an urban drainage system. In large cities, negative effects caused by the disorderly urbanization process, especially those related to rainwater runoff, are increasingly present. An evaluation model of urban drainage systems was generated using System Fragility Indicators (IFS) and their ranking via Analytic Hierarchy Process (AHP), in the Jaracati River basin, Maranhão State, Brazil. Indicators were measured through the evaluation of the system and the experience of specialists in drainage systems. The results obtained allowed for the consolidation of a model to support planning and decision-making in the assessment processes of measures to mitigate socio-environmental impacts involved in the urban drainage of a watershed, with performance indicators capable of guaranteeing the support of a model being verified measurement of performance parameters of urban drainage systems.

Keywords: AHP; system fragility indicators; rainwater runoff.

Received on April 6, 2022.
Accepted on September 20, 2022.

Introduction

The climate change scenario and changes in land use with the increase in the urbanization process can reduce soil permeability (Ebrahimian, Wilson, & Gulliver, 2016, (Ebrahimian, Gulliver, & Wilson, 2018; Malaekepour, Yazdandoost, & Tahmasebi Birgani, 2013), combined with inefficient drainage systems, increasingly generate flooding in urban centers (Panos et al., 2021)(Dong, Huang, & Zeng, 2017; Pappalardo & La Rosa, 2020), causing significant impacts on society and the environment (Shariat, Roozbahani, & Ebrahimian, 2019; Yin, Zheng, Duan, Zhang, & Bi, 2020).

Such factors, linked to multiple and adverse impacts of weather conditions and floods on urban infrastructure (Karamouz, Hosseinpour, & Nazif, 2011), have significantly increased the interest in improving drainage systems (Wang, Fang, & Sweetapple, 2021), as well as the development of efficient and sustainable systems to achieve satisfactory and environmentally sound urban stormwater management.

To deal with these floods, there is a need to develop adequate projects of urban drainage systems (UDS), given their functionality, incisively influencing the severity of the floods (Wang et al., 2021; Yin et al., 2020). In the context of studies on the importance of drainage systems, Sohn, Brody, Kim, and Li (2020) evaluated the impacts of three systems (based on storage, transport, and infiltration) to check their importance. Zhao et al. (2021) conducted a study to highlight the role of urban drainage systems in preventing surface water pollution. Zhou, Leng, Su, and Ren (2019) evaluated the efficiency of urban drainage in mitigating urban flooding.

Highlighting the importance of drainage systems, it must be understood that their failure or poor performance can lead to risk of flooding (Shariat et al., 2019). In this sense, it is necessary to carry out studies capable of measuring the performance levels of these flood mitigation mechanisms to improve urban development, which encourage constant research with common objectives, as in Wang et al. (2021), who evaluated a simple rainwater drainage network in seven sub-basins to obtain average values of flood durations and, in this way, implement forms of intervention. Pappalardo and La Rosa (2020) proposed policies for sustainable drainage systems in urban contexts within performance-based planning approaches. Ferguson and Fenner (2020) also assessed the impact of natural flood management on the performance of drainage systems.

Considering these problems and, at the same time, to have greater control over the efficiency levels of drainage systems (Lee & Gharaibeh, 2020), the literature makes use of analysis methodologies capable of measuring and assessing the performance of these systems, as in Panos et al. (2021), where the resilience assessment was used to evaluate climate change impacts on urban runoff. The authors state that climate change and redevelopment land use change impact stormwater runoff similarly. Mugume, Gomez, Fu, Farmani, and Butler (2015) performed a global analysis approach to investigate structural resilience in urban drainage systems in Uganda.

The need to use tools capable of improving and evaluating the efficiency of drainage systems evidences the development of processes involving multiple criteria and decision-making for sustainable urban development (Yang & Zhang, 2021), multi-criteria decision-making methods (MCDM) are used, such as Fuzzy Decision Approach (FDA) based on Fuzzy (Liang & Wang, 1991), Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) proposed by Hwang and Yoon (1981), Analytical Hierarchy Process (Saaty, 1977), Analytic Network Process (AHP) by Saaty (2008) and Measuring Attractiveness by a Categorical Based Evaluation Technique (MACBETH) developed by Bana e Costa and Vansnick (1994).

One of the best-known methods to support the decision-making process is the Analytic Hierarchy Process, which helps the decision-making process objectively by the appropriate classification of decision variants (Wolnowska & Konicki, 2019). The idea of the method is to break down a complex problem into simpler elements and apply expert opinions based on peer comparison (Bian, Hu, & Deng, 2017).

In the context of MCDM techniques and applications for drainage, Tahmasebi Birgani and Yazdandoost (2018) used the combined and adaptive multicriteria decision-making technique TOPSIS to check the behavior of urban drainage systems against floods, as well as their sustainability for urban managers. Shariat et al. (2019) used a risk analysis framework based on MCDM and fuzzy set theory to consider the criteria affecting the risk of flooding in urban areas, as well as their consequences. In the context of the application of AHP in drainage systems, due to operational and mathematical facilities, it has been widely applied (Ahmadisharaf, Kalyanapu, & Chung, 2016; Radmehr & Araghinejad, 2015; Tahmasebi Birgani & Yazdandoost, 2018). Wang, Sun, and Sweetapple (2017) performed storage site optimization in an urban stormwater drainage system using a two-stage approach. Benzerra, Cherrared, Chocat, Cherqui, and Zekiouk (2012) used the AHP as decision support for the implementation of drainage system management in Algeria. Yang and Zhang (2021) evaluated the performance of these systems using AHP and mathematical quantification to balance comprehensiveness and objectivity in the performance evaluation.

According to Tarigan, Rahmad, Sembiring, and Iskandar (2018), from the 1980s onwards, with the advent of the concept of sustainable development, there was a need to develop tools to measure and qualify the progress achieved with sustainability measures. For Benzerra et al. (2012), the use of indicators serves to weigh the progress of public policies and assist in decision making. Reis, Oliveira, and Sales (2008) discuss the need to develop weighting and planning methodologies.

Urban development without respecting the subdivision of the land has caused several disorders over the years. Urban management has become of great importance to mitigate the effects of floods. Due to recurrent interventions and to ensure higher management effectiveness, it is necessary to carry out monitoring using tools that can direct efforts and control measures of interventions carried out in the environment (Benzerra et al., 2012).

The search for indicators that demonstrate the environmental, social, and urban behavior of regions is essential for planning and actions by public agencies regarding drainage systems. Frailty indicators serve as parameters to assess the quality and efficiency of urban drainage systems (Kamil, Alias, Mohammed, Putrì, & Kalani, 2013; Tarigan et al., 2018). Thus, the use of System Fragility Indicators (SFIs) becomes an indispensable element regarding the measurement and demonstration of points of different types that require investments due to lack of efficiency (Tarigan et al., 2018).

The selection of types of natures for categorization of system fragility indicators should be one of the directional pillars as proposed by Doubleday, Sebastian, Luttenschlager, and Bedient (2013), who emphasized that indicators are parameters selected from characteristics of the analyzed system, important for reflection regarding certain conditions of the system under study.

In this sense, given the importance of studies capable of verifying and evaluating the performance of urban drainage systems, the present study aimed to build an analysis model of urban drainage systems as an evaluation tool using System Fragility Indicators (IFS) and hierarchy with the Analytic Hierarchy Process (AHP), using the Jacarati River basin as a case study, to consolidate a model to support planning and decision-making to mitigate socio-environmental impacts.

Material and methods

Regarding the methodological process adopted, this consisted of the use of the Analytic Hierarchy Process (AHP) method, with the use of System Fragility Indicators (IFS), for evaluating the efficiency of urban drainage system performance indicators. These methodologies are widely used in the literature, as in Tahmasebi Birgani and Yazdandoost (2018), Wang, Sun, and Sweetapple (2017), Tarigan et al. (2018) and Benzerra et al. (2012).

The selection process of the used multi-criteria model initially depended on the characteristics of the system, the decision-makers preference, and the type of result desired. The AHP was the method that best suited the problem, as it allows the ranking of alternatives, the creation of a hierarchical structure at various levels, in addition to being an easy-to-understand method, with broad practical application, a vast number of scientific publications, and availability of free software.

From the hierarchy model generated and operationalized for hierarchy of indicators, the census responses generated by the questionnaires applied to specialists provided a hierarchical comparison that supported suggestions for decision making. Figure 1 shows the representation of the stages of the analysis model of urban drainage systems that were operationalized.

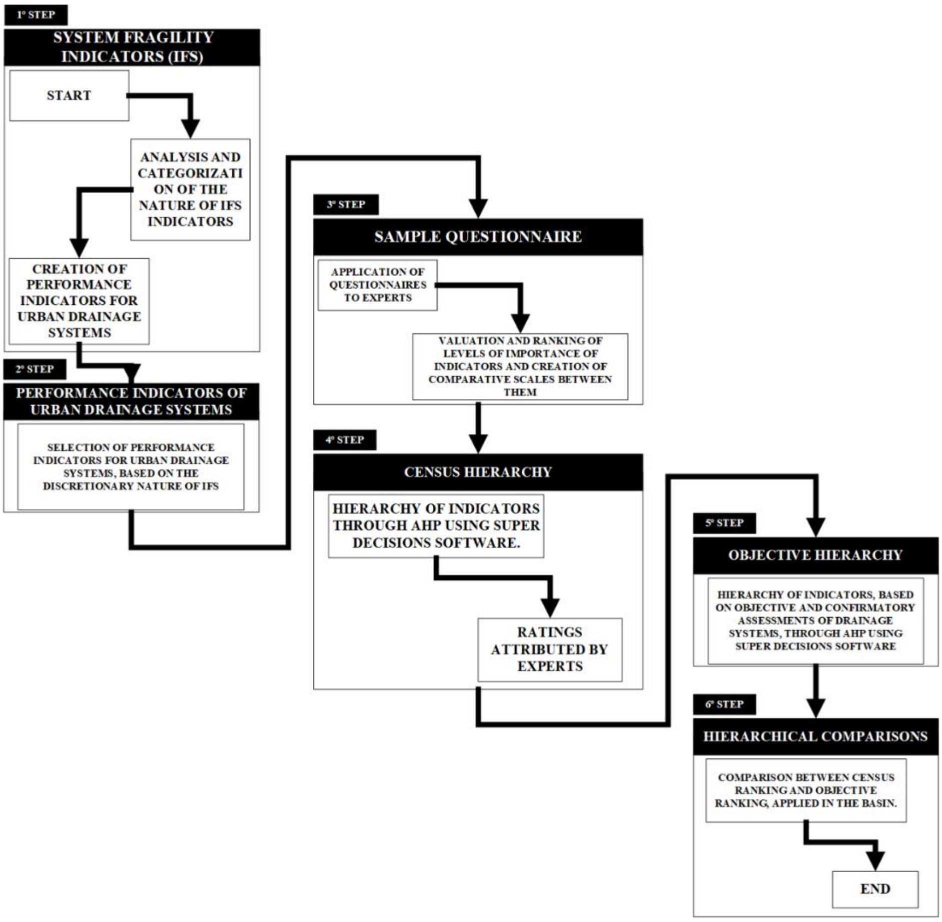

Figure 1. Methodological steps.

Analytic hierarchy process (AHP)

The AHP decision support multi-criteria judgment method was based on an active assessment methodology, in which multiple relevant characteristics were represented based on their respective importance. This process is characterized by the division of the problem into descending hierarchical levels, starting with the global target, criteria, sub-criteria, and possibilities in consecutive levels (Saaty, 1977).

According to Saaty (2008), the Analytic Hierarchy Process (AHP) is a very common analytical approach used in academic research, being seen as multi-criteria and having decision-making methods that can be applied to identify quantitative or qualitative evaluation criteria. Thus, relationships between the criteria are broken down and synthesized until a prioritization of their indicators is reached, approaching a better response of single performance measurement.

The problem was then hierarchically structured in such a way that criteria identified at each level are homogeneous and non-redundant, that is, they present the same degree of relative importance within their level (homogeneity) and are independent concerning the criteria of the levels lower (non-redundancy). This simple hierarchy structure for the AHP method is evidenced in Figure 2.

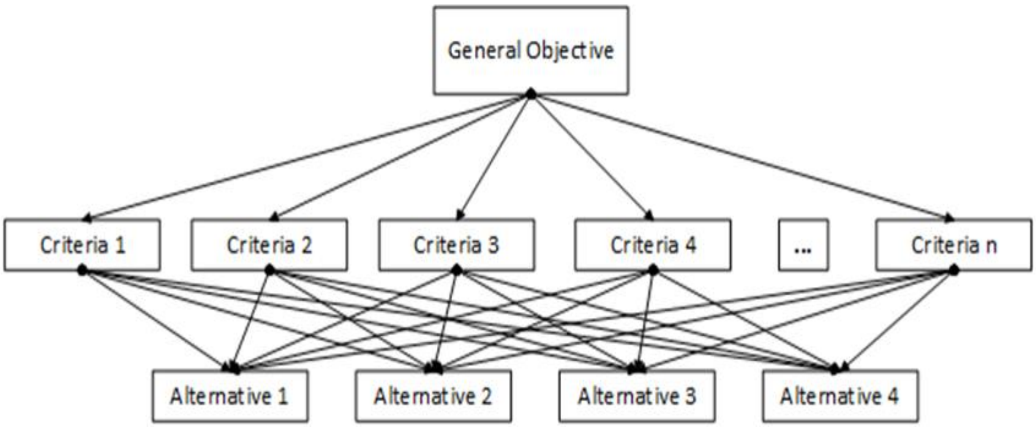

Figure 2. Hierarchical model of the AHP method. Source: Adapted from Saaty (2008).

The structuring for decision making involved multi-criteria structure in choosing a hierarchy, evaluating the relative importance of criteria, and delimiting alternatives for each criterion, generating a total ranking of alternatives. The weight of individual factors at the lowest level of the hierarchy influenced its maximum factor, which allowed a better structuring of a system and its functions, the measurement, and the impact of each element in the hierarchy.

Regarding the comparison between items, this worked from the relative scale of importance between two proposals, conceived by Saaty (2008), is the most used, assigning values between 1 and 9, disregarding the comparisons between the criteria themselves, which represents 1 on the scale. Thus, only half of the comparisons were made, given that the other half consisted of reciprocal comparisons in the comparison matrix, with values already compared.

Usually, we tried to use the odd numbers in the table, to ensure a reasonable distinction between the measurement points. The use of even numbers should only be adopted when there is a need for negotiation between evaluators and when a natural consensus is not reached, generating the need to determine a midpoint as a negotiated solution. Comparisons were implemented according to Saaty's fundamental scale, which ranges from 1 to 9, as shown in Table 1.

Table 1. Fundamental Scale of Pairwise comparison. Source: Adapted from Saaty (2008).

The intensity of assessment Scale	Assessment scale meaning
1	Equally Important
3	Moderately Important
5	Important
7	Very Important
9	Extremely Important
2, 4, 6, and 8	Intermediate Values of Important

Subsequently, the matrix in pairs was organized in the form of an n x n matrix. Criterion a_{ij} was obtained from expert judgments, using the evaluation intensity scale presented by Saaty (2008). Based on this, the lower triangular matrix; a_{21}, a_{ji} and a_{j2} can be calculated using the values of the upper diagonal; a_{12}, a_{ij} and a_{2j}, as evidenced in Equation 1.

$$M = \begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix} = \begin{bmatrix} 1 & a_{12} & a_{ij} \\ \frac{1}{a_{12}} & 1 & a_{2j} \\ \frac{1}{a_{ij}} & \frac{1}{a_{2j}} & 1 \end{bmatrix} \quad (1)$$

where a_{ij} represents the matrix elements that are the criteria comparison scales, i and j are the matrix rows and columns, respectively.

After organizing the matrix, the weight value of the comparison between pairs of attributes was calculated based on Equation 2 given in the literature by Rahman and Najib (2017).

$$C_k = \frac{1}{n} \sum_{j=1}^{n} \left(\frac{a_{kj}}{\sum_{i=1}^{n} a_{ij}} \right) \quad (2)$$

where k is an integer (K = 1, 2, 3, ..., n); a-$_{ij}$ represents the input of a given row and column compared to a matrix of order n.

The validity of the analysis is verified using the Consistency Ratio (CR), in which the values referring to this variable must be equal to or less than 0.10, as indicated in the literature in Yang and Xu (2002). To calculate this index, the Consistency Index (CI) is first calculated from Equation 3.

$$\text{CI} = \frac{\lambda \max - \text{n}}{\text{n}-1} \quad (3)$$

where λmax is the largest eigenvalue of the matrix of judgments and (n – 1) represents the number of degrees of freedom of the matrix. From the calculation of the CI value, the CR value can be calculated based on Equation 4.

$$\text{CR} = \frac{\text{CI}}{\text{RI}} < 0.1 \sim 10\% \quad (4)$$

The Random Consistency Index (RI) shown in Equation 4 can be calculated based on Saaty (2008), from Table 2, which is calculated for square matrices of order n (Dong & Cooper, 2016).

Table 2. Random consistency index, RI of matrix size. Source: Adapted from Saaty (1990).

Matrix Order (n)	1	2	3	4	5	6	7	8	9	10	11
RI Values	0	0	0.58	0.9	1.2	1.24	1.32	1.41	1.45	1.49	1.51

According to (Saaty & Kearns, 2014) from the point of view of the AHP, the CR of any comparison matrix should be less than or equal to 0.10 (10%), which would be considered consistent, that is, a reliable system. The higher the CR result, the more inconsistent the matrix. For values greater than 0.10, a review of the comparison matrix is recommended.

Performance indicators of urban drainage systems

The creation of indicators was supported by the entire methodological, mathematical and multicriteria framework of the AHP, aiming at a structured feeding and operationalization of the *Super Decisions software*. In this way, clusters of indicators were modeled, which were divided into three, namely: Cluster of Environmental Nature, Cluster of Technological Nature, and Cluster of Institutional Nature.

Each cluster was composed of six indicators. The number of indicators contained in each cluster was based on directs from (Saaty & Kearns, 2014) and (Ozcan & Musaoglu, 2010), as the purpose of a hierarchy is to group the most important elements and the least important elements of a hierarchy jointly and in the same operational phase of the composition of each consistency matrix.

Table 3 lists the details of these indicators based on each type of analysis. The acronyms observed in the table are in parentheses, they were defined to facilitate the naming of variables/indicators when implementing the consistency matrices in the AHP method in the Super Decisions software.

Census information questionnaire

Aiming at collecting census information, through the attribution of weights, about the valuation of urban drainage performance indicators used in the study, questionnaires were applied to a sample of 20 (twenty) professionals working in the urban drainage area.

The questionnaires consisted of the evaluation of indicators by specialists, with the aim that their empirical knowledge would generate quantitative data for analysis. Following the AHP process, the questions were asked giving importance values, based on the Saaty table, which ranges from 1 to 9. After pairwise comparison of the items developed from the used questionnaire, the summary of the results was treated and, later, used to feed the Super Decisions Software.

Table 3. Indicators defined with IFS.

Clusters of natures	Indicator (Criteria)
Technological	- Capacity and efficiency of collection of micro drainage devices and runoff on roads (CECDME) - Capacity and efficiency of collection and flow in macro-drainage devices (CECEDM) - Lessening of urbanization and waterproofing of surfaces in urban areas (MUISAU) - Mitigation of obstruction, by deposition of garbage and sediment, of rivers, channels, and galleries (MODLS) - Implementation of structural and non-structural control measures (IMCENE) - Sizing of micro and macro drainage systems based on IDF curves and consistent design hydrograms (DSMMB)
Environmental	- Physical degradation of land adjacent to channels (DFTAC) - Increase in sediment production (APS) - Occupation of areas prone to flooding and flooding (OAPAE) - Deposition of waste on roads (DRV) - Sedimentation of channels and galleries (ACG) - Increase in temperature due to urbanization processes (ATFPU)
Institutional	- Compliance with master and zoning plans (APDZ) - Compliance with state and municipal laws (ALEM) - Performance of public bodies in the control of structural and non-structural measures (AOPCMENE) - Public investments in drainage works (IPOD) - Population awareness programs to reduce environmental impacts (PCPMIA) - Impact Mitigation Projects (PMI)

Super Decisions software is a analytical network process (ANP) and AHP for decision making with linkage and feedback developed by Ph.D. Thomas Saaty. This program was documented by the ANP Team, which works for the Creative Decisions Foundation. The choice of software to automate mathematical interventions was Super Decisions software, as it promotes decision making, in the first place, by supporting the consistency index at the time of each judgment. It is still simple to generate modifications such as: adding, deleting criteria or choices, as well as exchanging evaluations.

For systematization of the data collection process of the questionnaires, the Google Forms platform was used, which allowed the quick and efficient collection of information with the specialists, as well as the management of events and the formulation of a statistical basis for the data collected.

Census hierarchy

The census hierarchy was selected for the method for not only comparing different objects generating a mathematical model but also for enabling the use of empirical knowledge for this purpose. In this way, the opinion of specialists is absorbed from the application of questionnaires filled in with values of importance, based on the Saaty scale.

In terms of defining objectives, criteria, and sub-criteria, it is noteworthy that the input of data and the operationalization of the AHP model in the super decisions software, adopted for the hierarchy and ranking of performance indicators of drainage systems, followed in its entirety, the hierarchical structure proposed in Table 3 and summarized in Table 4.

Table 4. Model hierarchy in AHP.

Level 1 - Objective	Level 1 2 - Criteria	Level 3 – Subcriteria/Alternatives
Objective	Technological	CECDME CECEDM MODLS MUISAU IMCENE DSMMB
	Environmental	DFTAC APS OAPAE DRV ACG ATFFPU
	Institutional	APDZ ALEM AOPCM IPOD PCPMIA PMIA

Objective hierarchy

For the objective hierarchy, the results referring to the case study from the application of the IFS were used. According to Table 5, weights from 1 to 5 were assigned according to the degree of manifestation of the indicator, which varies from "present, without aggravating factors" to "Absent, very aggravating". These values were added together to form the General Fragility Index, for Environmental, Technological, and Institutional natures.

Table 5. Values for evaluating the manifestation of indicators.

Values (weights)	Manifestation of the indicator
1	Present, without aggravating
2	Little Aggravating
3	Average
4	Moderate
5	Absent, very aggravating

Source: Santos and Cruz (2013).

The process consisted of measuring the indicators and assigning weights according to the degree of occurrence. The General Frailty Index (IGF) is the sum of scores listed by each indicator, the higher the result, the greater the degree of fragility. The variation in minimum and maximum values was from 0 to 90, divided by intervals of the degree of fragility as shown in Table 6.

Table 6. Scores and ranges of Fragility.

Fragility Degrees	Manifestation of the indicator
Short	18-36
Average	36-54
Strong	54- 72
Very strong	72-90

Source: Santos and Cruz (2013).

To generate an improvement parameter or even an evaluation of actions to be taken in the drainage system of the basin, the weights found with the IFS in the AHP were first applied, to present how the indicators in question are prioritized and compare them with what the experts advised is the best. Thus, an adaptation was created between the table by Saaty (2008) so that the Super Decisions system could be fed.

Table 5 lists the adaptation between the system fragility values and the weights of importance of comparison of the AHP, so that the system could be fed and, therefore, the ranking of indicators was obtained for comparison. The Saaty comparison scale was followed, ranging from 1 to 9, and an adapted scale was created, with values equivalent to those in Table 7.

Table 7. Adaptation of fragility values and importance weight.

IFS	5	2	3	4	5
AHP	9	8 or 7	6 or 5	4 or 3	1 or 2

Hierarchical comparison

The hierarchical comparison referred to the analysis between the census and objective hierarchy. From the analysis data obtained, it was possible to generate a diagnosis of the basin that helped in the construction of steps for decision-making, following the order in which the ranking of criteria and sub-criteria was organized.

In this way, by prioritizing the hierarchy generated by the AHP in the Super Decisions Software, a more organized analysis was obtained for the points requiring more attention, in the urban drainage system, of a watershed. In this way, decision-making, mainly referring to control measures, prioritized the indicators demanding greater attention, according to the hierarchy ranking.

Case study

The case study took place in the Jaracati River sub-basin, municipality of São Luís, state of Maranhão. Due to its location close to the equator, the region has an average annual temperature of 27°C and according to the system proposed by Koppen (2023) the climate of São Luís is classified as Tropical Rainy (Af). The rainy season occurs from January to June, with an average of 200 mm rainfall, and from July to December is considered the dry season. Figure 3 illustrates the location of the Jaracati River basin.

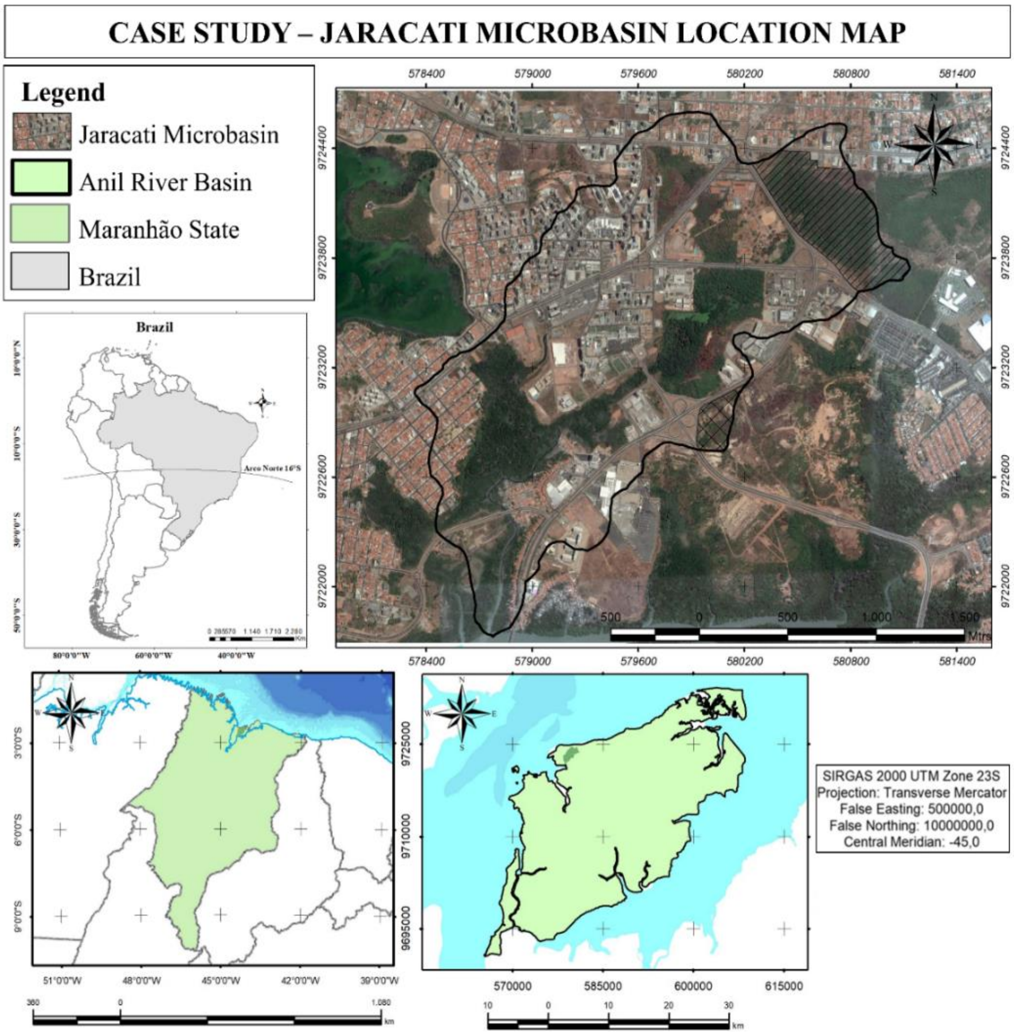

Figura 3. Jaracati Basin location map.

The Jaracati River is a major tributary of the Anil River basin. The model of analysis of urban drainage systems sought an analysis process that could be applied in different types of watersheds, and generate diagnoses and parameters for measurements and improvement according the results found, from what was suggested by specialists. In this way, the IFS supported the development of indicators, which the AHP ranked to order the analysis for decision making. Thus, with the defined method, it was possible to apply it, as was done in the case study, in the Jaracati River basin.

Application of the computational tool

With the organization of information Google Forms collected, the construction of the hierarchy in Super Decisions was obtained. As represented in Figure 4, there was an AHP tree diagram, from which each core is named by the system as clusters, divided into levels, in which the first refers to the objective (Goal), the second to the criterion level (Criteria) and the third level in this model is the subcriteria representing the nature indicators.

The structure in Figure 4 presents not only the organization of AHP in Super Decisions but also the desired model system; the work is limited only to hierarchizing the criteria and sub-criteria. According to the script based on the methodology, three types were chosen, but there is no restriction on the number of indicators for each type, however, considering the system consistency guided by the software manual, six indicators were defined (which were called subcriteria) for each, symbolized with their initials, in each subcriteria cluster.

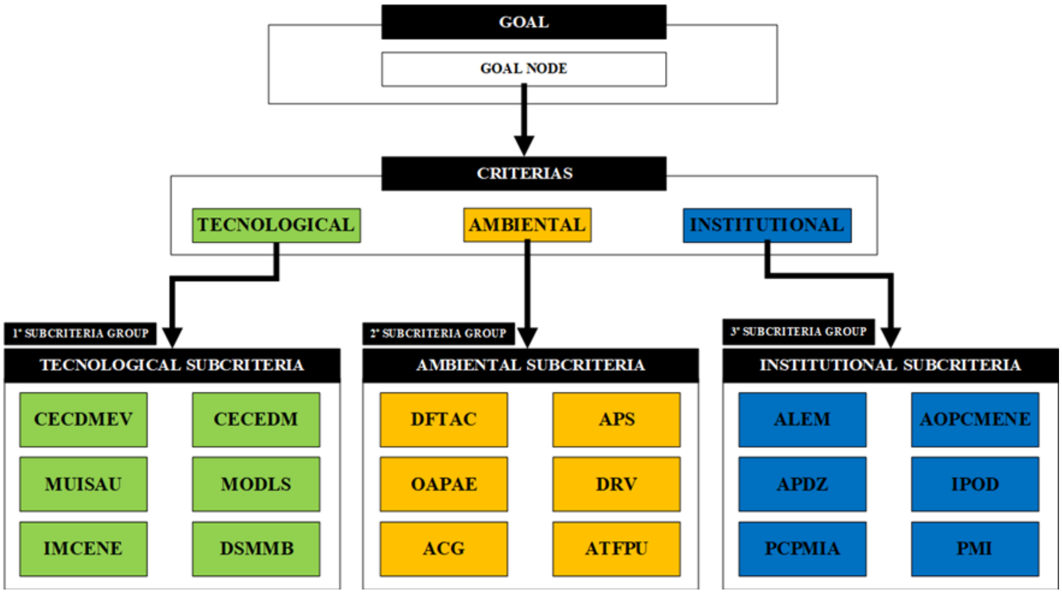

Figure 4. AHP structure in super decisions.

Results and discussion

After obtaining the values by the specialists, referring to the census hierarchy stage, together with the case study with the objective hierarchy, support was obtained for the elaboration of Table 8, whose function was to base comparisons to assist in analysis.

Table 8. General fragility index.

Nature	Indicator	Value
Technological	Capacity and efficiency of collection of micro drainage devices and runoff inroads	4
	Capacity and efficiency of collection and flow in macro-drainage devices	3
	Lessening of urbanization and waterproofing of surfaces in urban areas	2
	Lessening of obstruction, by deposition of garbage and sediments, of rivers, canals, and galleries	4
	Implementation of structural and non-structural control measures	4
	Sizing of micro and macro drainage systems based on IDF curves and consistent design hydrographs	5
Environmental	Physical degradation of terrain adjacent to channels	3
	Increase in sediment production	4
	Occupation of areas prone to flooding and flooding	4
	Deposition of waste on roads	4
	Sanding of channels and galleries	4
	Increase in temperature due to urbanization processes	3
Institutional	Compliance with master and zoning plans	4
	Compliance with state and municipal laws	4
	Performance of public bodies in the control of structural and non-structural measures	5
	Public investments in drainage works	4
	Population awareness programs to reduce environmental impacts	5
	Impact mitigation projects	3
	TOTAL	69

Table 9, read first by the column represented by criteria referring to nature, where they are in order of priority set by the specialists: environmental, technological, and institutional. The second column, specialists, follows the order of the census hierarchy stage, as the third column, refers to the objective case study. The order of indicators and their percentage values mention the importance of the specialists, how important the indicator is, and the case study to the extent to which that indicator demands attention due to its occurrence.

Based on these comparisons, possible measures or actions for changes are suggested, when necessary. The objective ranking showed that the Jaracati River basin has a degree of fragility, whose evaluation in the methodology defines as strong. Thus, the importance of omparing the values assigned by experts to those found.

Table 9. Expert Table x Case Study.

Nature		Specialists			Case Study	
		%	Indicator		%	Indicator
Environmental	1°	41,01%	DRV	1°	38,97%	DRV
	2°	30,84%	ATFPU	2°	37,56%	ACG
	3°	11,14%	DFTAC	3°	9,18%	DFTAC
	4°	9,62%	ACG	4°	9,05%	ATFPU
	5°	4,75%	APS	5°	2,62%	APS
	6°	2,64%	AOPAE	6°	2,61%	AOPAE
Technological	1°	42,05%	IMCENE	1°	30,00%	MOLDS
	2°	27,99%	MUISAU	2°	29,19%	CECEDM
	3°	15,43%	CECEDM	3°	27,70%	IMCENE
	4°	7,61%	DSMMB	4°	5,07%	CECEMEV
	5°	4,52%	MOLS	5°	5,15%	MUISAU
	6°	2,40%	CECECMEV	6°	2,62%	DSMMB
Institutional	1°	29,02%	PCPMIA	1°	41,39%	PCPMIA
	2°	24,92%	IPOD	2°	34,70%	AOPCME
	3°	16,16%	APDZ	3°	6,52%	ALEM
	4°	15,07%	ALEM	4°	7,99%	APDZ
	5°	12,02%	PMI	5°	7,23%	IPOD
	6°	2,81%	AOPCME	6°	2,16%	PMI

Source: Prepared by the authors (2021).

Figure 5 illustrates the analysis of data from environmental indicators, environmental nature is the first to be evaluated, obeying the importance given in the census hierarchy. The order of prioritization is also given by the decision of the experts, whose representation was made in the columns in black and gray at the value of occurrence in the case study.

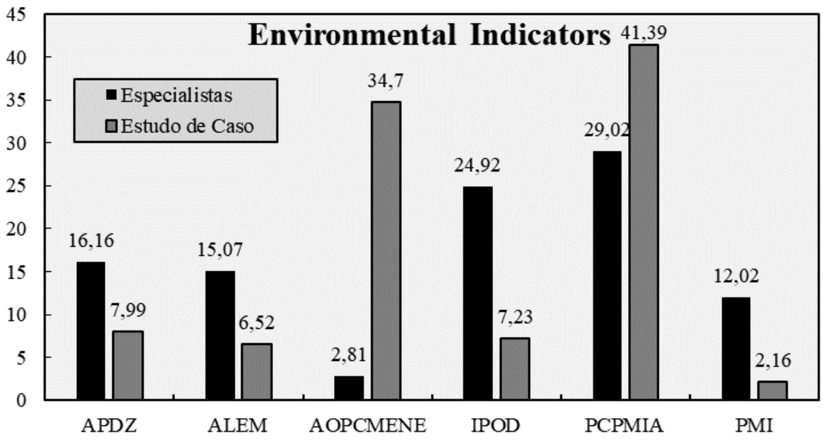

Figure 5. Environmental indicators - Experts x Case Study.

Both in the case study and the evaluation by experts, the indicator on physical degradation of land adjacent to channels (DRV) had the highest occurrence and deserved due attention, and its value in the case study was higher than accepted by specialists due to its high occurrence. Thus, control measures have to be taken, such as reducing pollution from urban waste and raising public awareness.

In the view of experts, the increases in temperature due to urbanization processes (ATFPU) indicator demands great attention of analysis, although in the case study have a low occurrence. This indicator offers a long-term assessment, as it is currently not manifested, but the behavior of other activities or the influence of other indicators may lead to the development of such an indicator.

Regarding the indicator nature, technology was second in the analysis stage, Figure 6 illustrates the comparison of experts' opinion to that found the case study. At first, several differences in priority can be noticed between the indicators, but it is important to emphasize that the key is the power to raise control measures for the studied basin.

The indicators referring to the Implementation of structural and non-structural control measures (IMCENE) and the Lessening of urbanization and waterproofing of surfaces in urban areas (MUISAU) were considered by experts as the indicators demanding greater attention of analysis, differently from that considered in the case study.

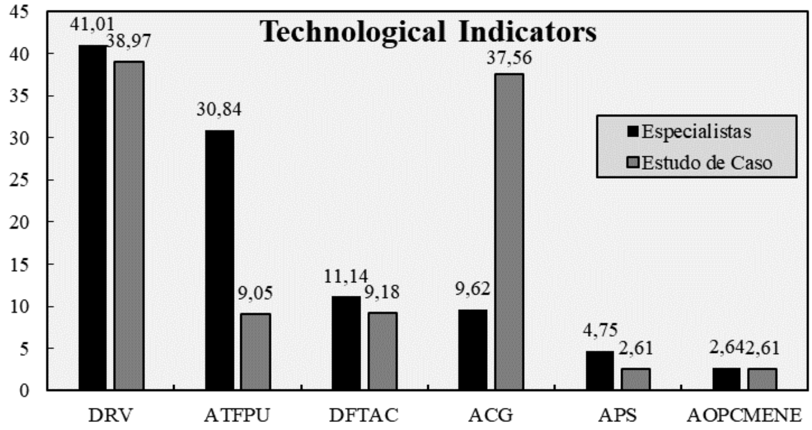

Figure 6. Technological indicators - Experts x Case Study.

Part of non-structural measures, related to decision-making to improve the indicators, comes from organizational issues, relevant to the watershed area. Initiatives that can be taken individually, however, demand stimulus from the management of the municipality, regarding environmental reeducation. Encouraging the sustainability of the municipality is fundamental in the urbanization process, even though experts suggested attention to indicators, such as the efficiency of macro-drainage devices of and road drainage (CECDMEV). Attitudes of the population, such as depredation or even dumping of sediments, cause inefficiency of the device and the agglomeration of waste when some flooding starts.

The institutional nature is the third and last in the Jaracati River sub-basin assessment process. Even though it is the last, indicators of this nature are essential for the good progress of drainage plans. Figure 7 presents the ranking of experts' opinion and the case study, in which the indicator referring to population awareness programs to reduce environmental impacts (PCPMIA) is of great importance.

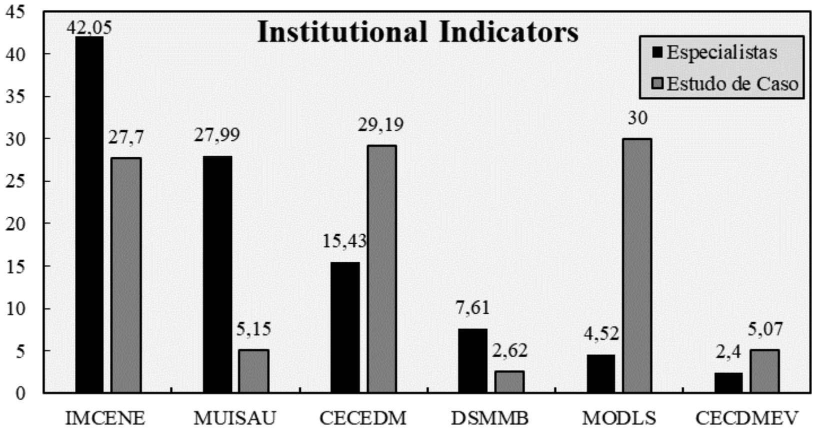

Figure 7. Institutional indicators - Experts x Case Study.

From the observation of the analyzed aspects, it was not possible to define which process steps are vital because, for the functioning of drainage systems, the natures have to be equated and controlled. Although data are not formalized, the important script created from the hierarchy of indicators enables to build management plans that effectively solve drainage problems.

The Jaracati River sub-basin has a strong degree of fragility, that is, a weakened drainage system, in which, environmental nature demands greater attention, based on indicators of degradation of adjacent lands and disorderly urbanization. The technological and institutional natures are, respectively, with indicators referring to the drainage structure and public policies, which corroborate the context of the basin, as they did not work effectively.

In the results found, it was possible to obtain a model of the analysis process of the basin, in which the hierarchical part has become fundamental to aid in decision making, all based on the opinion of experts and the reality found. The fundamental aspect of the study was not only to verify the fragility of the Jaracati River sub-basin but also to know which stages of analysis of indicators, according to each nature, and which measures may be appropriate.

Thus, based on the results, the first decision-making measures should be environmental, referring to reduction in deforestation and urbanization plans. Therefore, criteria of a technological and institutional nature demand municipal public policies to improve drainage structures and, above all, social education, such as not disposing solid waste on the roads.

The results indicated the direction, regarding the analysis process of the Jaracati River sub-basin, and the hierarchy about the decision-making regarding control measures. Therefore, this model admits flexibility to be able to model analysis of any hydrographic basin, presenting its conjuncture with a technical basis.

Planning and management of urban growth are vital for conservation of watersheds and control measures, such as management plans and master plans for drainage projects. The analysis process generated is a contribution to the development of analysis of any basin. Due to its flexibility in modeling according to existing demands, for future studies, it is necessary to compare basins to compare indicators and good preservation practices that encourage decision-making aimed at control measures.

Conclusion

Planning and management of urban growth are essential for conservation of hydrographic basins, especially about management plans and drainage projects. Providing evaluation parameters based on a judgment process generates greater security in decision-making regarding the control of urban drainage systems. Based on tools, such as the systems fragility index (SFI) and process hierarchical analysis (AHP), a model for measuring performance indicators of urban drainage systems is obtained, capable of analyzing cases such as that of the Jaracati River sub-basin. Undeniably the case study engaged a demonstration of demands and deficiencies commonly found, however, in a hierarchical and parameterized way from the proposed.

References

Ahmadisharaf, E., Kalyanapu, A. J., & Chung, E. S. (2016). Spatial probabilistic multi-criteria decision making for assessment of flood management alternatives. *Journal of Hydrology*, *533*, 365-378. DOI: https://doi.org/10.1016/j.jhydrol.2015.12.031

Bana e Costa, C. A., & Vansnick, J.-C. (1994). MACBETH - An interactive path towards the construction of cardinal value functions. *International Transactions in Operational Research*, *1*(4), 489-500. DOI: https://doi.org/10.1016/0969-6016(94)90010-8

Benzerra, A., Cherrared, M., Chocat, B., Cherqui, F., & Zekiouk, T. (2012). Decision support for sustainable urban drainage system management: A case study of Jijel, Algeria. *Journal of Environmental Management*, *101*, 46-53. DOI: https://doi.org/10.1016/j.jenvman.2012.01.027

Bian, T., Hu, J., & Deng, Y. (2017). Identifying influential nodes in complex networks based on AHP. *Physica A: Statistical Mechanics and Its Applications*, *479*, 422-436. DOI: https://doi.org/10.1016/j.physa.2017.02.085

Dong, Q., & Cooper, O. (2016). An orders-of-magnitude AHP supply chain risk assessment framework. *International Journal of Production Economics*, *182*, 144-156. DOI: https://doi.org/10.1016/j.ijpe.2016.08.021

Dong, X., Huang, S., & Zeng, S. (2017). Design and evaluation of control strategies in urban drainage systems in Kunming city. *Frontiers of Environmental Science & Engineering*, *11*(4), 1-4. DOI: https://doi.org/10.1007/s11783-017-0968-9

Doubleday, G., Sebastian, A., Luttenschlager, T., & Bedient, P. B. (2013). Modeling Hydrologic Benefits of Low Impact Development: A Distributed Hydrologic Model of The Woodlands, Texas. *JAWRA Journal of the American Water Resources Association*, *49*(6), 1444-1455. DOI: https://doi.org/10.1111/jawr.12095

Ebrahimian, A., Gulliver, J. S., & Wilson, B. N. (2018). Estimating effective impervious area in urban watersheds using land cover, soil character and asymptotic curve number. *Hydrological Sciences Journal*, *63*(4), 513-526. DOI: https://doi.org/10.1080/02626667.2018.1440562

Ebrahimian, A., Wilson, B. N., & Gulliver, J. S. (2016). Improved methods to estimate the effective impervious area in urban catchments using rainfall-runoff data. *Journal of Hydrology*, *536*, 109-118. DOI: https://doi.org/10.1016/j.jhydrol.2016.02.023

Ferguson, C., & Fenner, R. (2020). The impact of natural flood management on the performance of surface drainage systems: A case study in the Calder Valley. *Journal of Hydrology*, *590*, 1-8. DOI: https://doi.org/10.1016/j.jhydrol.2020.125354

Hwang, C. L., & Yoon, K. (1981). *Multiple attribute decision making* (v. 186). Berlin; Heidelberg, GE: Springer. DOI: https://doi.org/10.1007/978-3-642-48318-9

Yang, J.-B. & Xu, D.-L. (2002). On the evidential reasoning algorithm for multiple attribute decision analysis under uncertainty. *IEEE Transactions on Systems, Man, and Cybernetics - Part A: Systems and Humans*, *32*(3), 289-304. DOI: https://doi.org/10.1109/TSMCA.2002.802746

Kamil, I., Alias, B., Mohammed, A., Putrì, N. T., & Kalani, C. (2013). Design of performance evaluation tools for drainage of roads system in developing country (case study: drainage system for city roads in padang Indonesia). In *Proceedings of the International Symposium on the Analytic Hierarchy Process 2013*. DOI: https://doi.org/10.13033/isahp.y2013.035

Karamouz, M., Hosseinpour, A., & Nazif, S. (2011). Improvement of Urban Drainage System Performance under Climate Change Impact: Case Study. *Journal of Hydrologic Engineering*, *16*(5), 395–412. DOI: https://doi.org/1*0.1061/(ASCE)HE.1943-5584.0000317*

Koppen, K. (2023). *Koppen climate classification | Definition, System, & Map | Britannica*. Retrieved from https://www.britannica.com/science/Koppen-climate-classification

Lee, C.-C., & Gharaibeh, N. G. (2020). Automating the evaluation of urban roadside drainage systems using mobile lidar data. *Computers, Environment and Urban Systems*, *82*, 101502. DOI: https://doi.org/10.1016/j.compenvurbsys.2020.101502

Liang, G.-S., & Wang, M.-J. J. (1991). A fuzzy multi-criteria decision-making method for facility site selection. *International Journal of Production Research*, *29*(11), 2313-2330. DOI: https://doi.org/10.1080/00207549108948085

Malaekepour, S. M., Yazdandoost, F., & Tahmasebi Birgani, Y. (2013). Assessment of Climate Change Impact on IDF Curves: Case Study for Tehran- Iran. In *Proceedings of 2013 IAHR World Congress*.

Mugume, S. N., Gomez, D. E., Fu, G., Farmani, R., & Butler, D. (2015). A global analysis approach for investigating structural resilience in urban drainage systems. *Water Research*, *81*, 15-26. DOI: https://doi.org/10.1016/j.watres.2015.05.030

Ozcan, O., & Musaoglu, N. (2010). Vulnerability Analysis of Floods in Urban Areas Using Remote Sensing and GIS. In *Remote Sensing for Science, Education, and Natural and Cultural Heritag*e (p. 379-386). Paris, FR: EARSel. Retrieved from http://www.earsel.org/symposia/2010-symposium-Paris/Proceedings/EARSeL-Symposium-2010_9-02.pdf

Panos, C. L., Wolfand, J. M., & Hogue, T. S. (2021). Assessing resilience of a dual drainage urban system to redevelopment and climate change. *Journal of Hydrology*, *596*, 1-8. DOI: https://doi.org/10.1016/j.jhydrol.2021.126101

Pappalardo, V., & La Rosa, D. (2020). Policies for sustainable drainage systems in urban contexts within performance-based planning approaches. *Sustainable Cities and Society*, *52*, 1-3. DOI: https://doi.org/10.1016/j.scs.2019.101830

Radmehr, A., & Araghinejad, S. (2015). Flood vulnerability analysis by fuzzy spatial multi criteria decision making. *Water Resources Management*, *29*(12), 4427-4445. DOI: https://doi.org/10.1007/s11269-015-1068-x

Rahman, N. S. F. A., & Najib, A. F. A. (2017). Selection of the most practical Malaysian port for enhancing the Malaysia-China Kuantan Industrial Park business trade. *International Journal of Shipping and Transport Logistics*, *9*(4), 500-525. DOI: https://doi.org/10.1504/IJSTL.2017.084829

Reis, R. P. A., Oliveira, L. H., & Sales, M. M. (2008). Sistemas de drenagem na fonte por poços de infiltração de águas pluviais. *Ambiente Construído*, *8*(2), 99-117.

Saaty, T. L. (1977). A scaling method for priorities in hierarchical structures. *Journal of Mathematical Psychology*, *15*(3), 234-281. DOI: https://doi.org/10.1016/0022-2496(77)90033-5

Saaty, T. L. (2008). Decision making with the analytic hierarchy process. *International Journal of Services Sciences*, *1*(1), 83-98. DOI: https://doi.org/10.1504/IJSSCI.2008.017590

Saaty, T. L., & Kearns, K. P. (2014). *Analytical planning: The Organization of system*. Elsevier Science.

Santos, L. F., & Cruz, R. B. C. (2013). O uso do método AHP na tomada de decisão para seleção de sistemas de lajes de edifícios comerciais. *Engenharia Estudo e Pesquisa*, *13*(1), 39-52.

Shariat, R., Roozbahani, A., & Ebrahimian, A. (2019). Risk analysis of urban stormwater infrastructure systems using fuzzy spatial multi-criteria decision making. *Science of The Total Environment*, *647*, 1468-1477. DOI: https://doi.org/10.1016/j.scitotenv.2018.08.074

Sohn, W., Brody, S. D., Kim, J.-H., & Li, M.-H. (2020). How effective are drainage systems in mitigating flood losses? *Cities*, *107*, 102917. DOI: https://doi.org/10.1016/j.cities.2020.102917

Tahmasebi Birgani, Y., & Yazdandoost, F. (2018). An Integrated Framework to Evaluate Resilient-Sustainable Urban Drainage Management Plans Using a Combined-adaptive MCDM Technique. *Water*

Resources Management, *32*(8), 2817–2835. https://doi.org/10.1007/s11269-018-1960-2

Tarigan, A. P. M., Rahmad, D., Sembiring, R. A., & Iskandar, R. (2018). An application of the AHP in water resources management: A case study on urban drainage rehabilitation in Medan City. *IOP Conference Series: Materials Science and Engineering*, *309*, 1-8. DOI: https://doi.org/10.1088/1757-899X/309/1/012096

Wang, M., Fang, Y., & Sweetapple, C. (2021). Assessing flood resilience of urban drainage system based on a 'do-nothing' benchmark. *Journal of Environmental Management*, *288*(15), 1-3. DOI: https://doi.org/10.1016/j.jenvman.2021.112472

Wang, M., Sun, Y., & Sweetapple, C. (2017). Optimization of storage tank locations in an urban stormwater drainage system using a two-stage approach. *Journal of Environmental Management*, *204*(1), 31–38. DOI: https://doi.org/10.1016/j.jenvman.2017.08.024

Wolnowska, A. E., & Konicki, W. (2019). Multi-criterial analysis of oversize cargo transport through the city, using the AHP method. *Transportation Research Procedia*, *39*, 614–623. DOI: https://doi.org/10.1016/j.trpro.2019.06.063

Yang, W., & Zhang, J. (2021). Assessing the performance of gray and green strategies for sustainable urban drainage system development: A multi-criteria decision-making analysis. *Journal of Cleaner Production*, *293*, 126191. DOI: https://doi.org/10.1016/j.jclepro.2021.126191

Yin, H., Zheng, F., Duan, H.-F., Zhang, Q., & Bi, W. (2020). Enhancing the effectiveness of urban drainage system design with an improved ACO-based method. *Journal of Hydro-environment Research*, *38*, 96-105. DOI: https://doi.org/10.1016/j.jher.2020.11.002

Zhao, X., Zheng, Y., Hu, S., Qiu, W., Jiang, J., Gao, C., Xiong, J., Lu, H., & Quan, F. (2021). Improving urban drainage systems to mitigate PPCPs pollution in surface water: A watershed perspective. *Journal of Hazardous Materials*, *411*, 125047. DOI: https://doi.org/10.1016/j.jhazmat.2021.125047

Zhou, Q., Leng, G., Su, J., & Ren, Y. (2019). Comparison of urbanization and climate change impacts on urban flood volumes: Importance of urban planning and drainage adaptation. *Science of The Total Environment*, *658*, 24-33. DOI: https://doi.org/10.1016/j.scitotenv.2018.12.184