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URBAN FLOODS MANAGEMENT USING AHP AND FMEA METHODS—CASE STUDY OF BEJAIA, ALGERIA

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Abstract: This study aims to help the management of the Stormwater Drainage System (SDS) of Bejaia City to manage urban flood problems, i.e., to provide them with tools for a better organization of information on SDS combined with a better optimization of its interventions on the network. Our study is based on a multicriteria analysis of the "SDS–inundation–Impact" system. We used a multicriteria approach and classified the overflow points called Black Points (BPs) using two methods: Analytic Hierarchy Process (AHP) and Failure Mode, Effect and criticality Analysis (FMEA). The criteria and the evaluation scale were defined on the basis of past observations, expert opinions, and feedback experience. The map of the past flooded areas was made and used to calibrate the two models. We mapped the BPs according to intervention priorities (one to four). The outcomes from both models are greatly comparable to the results of the impact assessment of past floods. The proposed approach can also reduce flood risks by integrating some of influencing factors (causing floodings) and the application can be adapted and implemented in other cities too. Both methods are reliable, particularly the AHP for the most overflowing BPs. They could be advantageously combined to improve decision-making.

Keywords: urban floods; Stormwater drainage systems; multicriteria approach; AHP & FMEA; overflow points

1. Introduction

The management of floods due to stormwater network overflows has been the subject of numerous studies. Generally, the studies relied primarily on the multicriteria analysis, mapping, database, or GIS and remote sensing. Some authors proceed to urban flood impact assessment (Hammond et al., 2015), development of a method for characterizing and evaluating the human risk related to flooding in urban areas (Marion, 2016), application of the Functional Resonance Analysis Method (FRAM) for the qualitative risk analysis of multifunctional flood defenses (Anvarifar et al., 2017), a stress test of urban system flooding upon extreme rainstorms in Hong Kong (He et al., 2021), agent-based modeling and flood risk management (Zhuo & Han, 2020), mapping flood risk (Ouma et al., 2014), flood

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mapping per representation of the risk at the intersection of hazard and vulnerability (Renard & Soto, 2015), urban flood vulnerability zoning using remote sensing and GIS (Sowmya et al., 2015), integration of GIS and Hierarchical Multicriteria Analysis for Mapping Flood Vulnerability (Loumi & Redjem, 2021).

The simulation is essential for overflows study, but is not always applied to the Stormwater Drainage System (SDS) system study, due to several possible causes, unavailability of data, and difficulty of predicting the factors that cause these malfunctions (Caradot et al., 2011; Granger et al., 2013). For this reason, our study is characterized by diversified approaches leading to varied methods adopted for exploitation of the existing data.

The SDS of Bejaia City is frequently flooded due to heavy rains on the one hand and the state of the stormwater network (frequent fouling and hydraulic insufficiency particularly) on the other hand. Each time, these floods cause significant damage and inconvenience (hindrance or blockage of traffic, sewerage water intrusions into homes, etc.), particularly in the lower part of the city where it is the busiest. Without an effective strategy and tools, network managers are struggling to manage flooding problems. The inundation phenomenon became arduous and decision-makers face the challenge of effectively adapting a strategy in response to frequent and unexpected urban flooding.

Therefore, the study's goal is to develop a simple and reliable method which allows to classify the Black Points (BPs) according to the importance of their impact on the city. This will permit to prioritize network rehabilitation and flood management interventions and thus optimize the cost and response times.

As specified in Section 3, we have adopted two methods, Analytic Hierarchy Process (AHP) and Failure Mode, Effect and criticality Analysis (FMEA). These methods are of great interest to authors in several research areas. AHP is used in this study because it is a structured decision-making technique based on mathematics and psychology. Several urban flooding risk studies have used this technique for its simplicity and robustness (Ayari et al., 2016; Philippe et al., 2018). Indeed, it allows to check the consistency of the important relationships between the criteria (Benbachir et al., 2020), to strengthen the robustness of the SDSs performance evaluation methodology in terms of rain overflows, calculate a coherence index permitting to evaluate the judgments rendered (great advantage), and finally, to have a valid tool to make the best decisions since its application allows convergence toward a choice shared between different decision-makers who express their preference in the judgments on the criteria and sub-criteria of comparison.

FMEA is based on precise criteria. It was originally designed in studying of very well-known industrial processes, and on which, in particular, precise data concerning the history of past failures were available, as well as their consequences and delays in bringing the system back into service after a failure (Dyadem Press, 2003; Stamatis, 2003). This approach was adapted to the data and knowledge available on the studied SDS. The method is based on the estimation of a criticality index (I_c) which is based on a set of criteria permitting to highlight the BPs) most sensitive to overflow risks.

2. Study area

Bejaia is a coastal town located 260 km east of Algiers, with an area of nearly 120.22 km^2 (ONA, 2017; Figure 1). Thanks to its geographical location, Bejaia is a tourist city with international airport and one of the largest oil ports in the Mediterranean Sea.

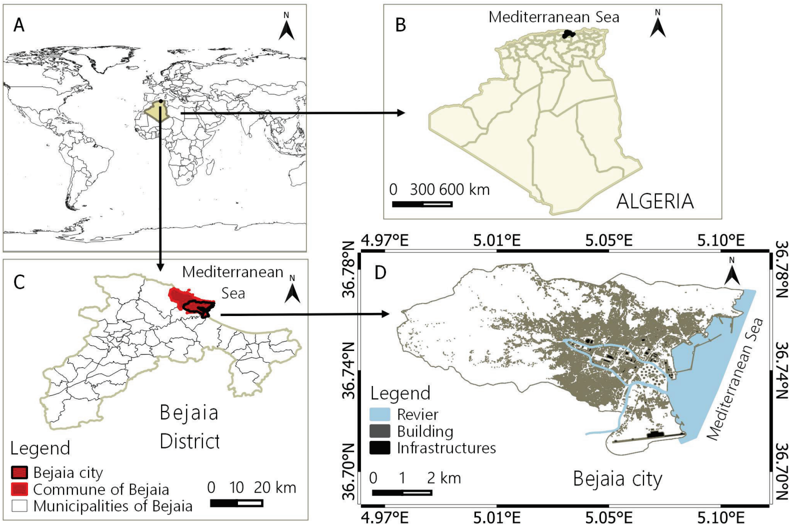

Figure 1. Location of the City of Bejaia (D) on a global (A), national (B), and provincial scale (C).

Its SDS total length is approximately 359 km with totally gravity flows (ONA, 2017). Figure 2 illustrates the Bejaia SDS size and the different morphological characteristics. The pipes are mainly circular, 92% of which are sections (diameters) varying from 200 to 650 mm, 7.6% are sections from 700 to 1,500 mm, the rest are sections greater than 1,500 mm (ONA, 2017). The rest of great collectors are open or closed canals.

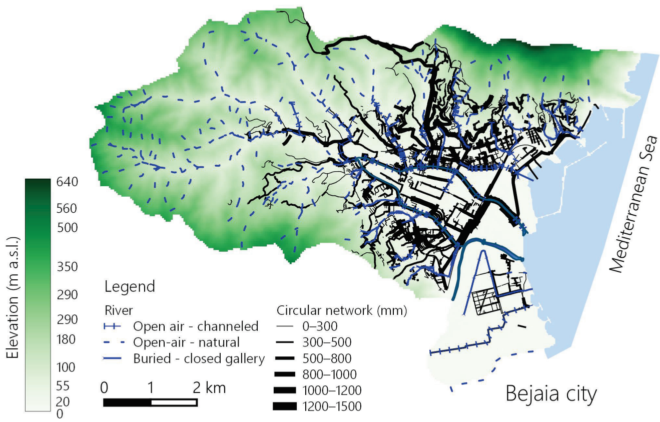

Figure 2. Stormwater drainage system of Bejaia City.

The site topography reveals three types of slopes: low (0.6 to 2%, 20% of watershed, mostly downstream of the SDS with strong urbanization density), medium (2 to 4%, 6% of the global area with average to strong urbanization density), and strong (6 to 34%, 74% of the watershed, mostly upstream of the network with a mix of wood and urban areas) (ONA, 2017). The relief of the land, increasing urbanization and defects in the SDS give rise to the most dangerous form of flooding occurring in the spring and summer periods.

3. Methodology

The methodology developed will be used to deal with future floods likely to recur in the city, being inspired by the past floods. Figure 3 presents the approach used to realize this study and some associated criticisms illustrating encountered difficulties and constraints.

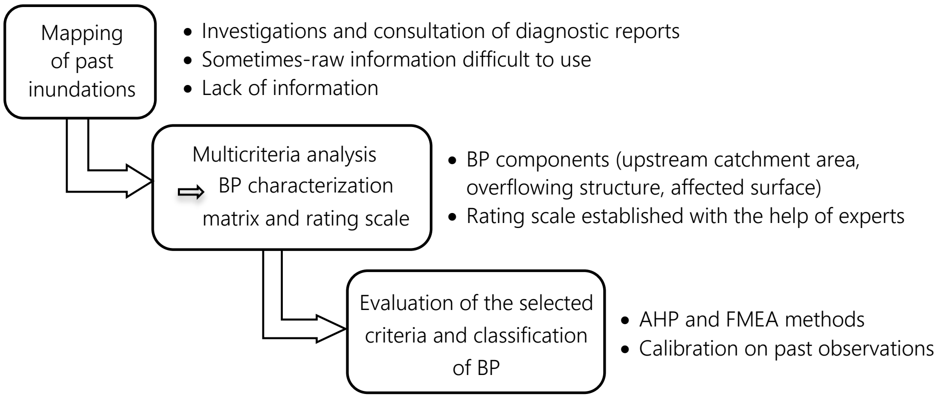

Figure 3. Methodological organization chart to assess the selected criteria and performances.

3.1 Mapping of past inundations

In order to map the SDS overflows in Bejaia city, we need to:

- Collect and process data and information relating to overflows recorded in the past.
- Draw up SDS BPs maps (overflowing points; Figure 4A) and flooded areas (Figure 4B). The maps helped us to:
  - Locate and characterize the flooded places and establish the causes (clogging of the downstream network, hydraulic inability, or other possible failure).
  - List and locate various damage and impacts: important parameters for evaluating the sensitivity of places affected by overflows and defining an evaluation scale.

We have established the ranking of BPs based on the performance scale in Figure 4C and it is illustrated in Figure 4D.

3.2 Multicriteria analysis—Evaluation scale and criteria

Different criteria allow assessing importance of a BP (Bruwier, 2020; Pradeep & Wijesekera, 2020; Qi et al., 2020), and the most influential of them were selected in this study. Table 1 presents the scale adopted to assess and score the used criteria with direct or indirect relations with SDS's floods.

Twelve criteria have been defined and classified into two types: impact criteria (C_1 to C_4) and influence criteria (C_5 to C_{12}). The first were established on the basis of diagnostics carried out locally (analysis of past floods and their impacts on the population and urban activities: example of Figure 4B, impacts of past floods, etc.), and opinions of experts and field agents. The extent of these impact criteria was observed in particular in the flat part of the city (downstream of the network) where the activities are the most important. The second are criteria whose influence on urban runoff is obvious and known in urban hydrology. Several similar studies have used these criteria according to the specificities of the sites studied (Eini et al., 2020; Ouma et al., 2014; Stefanidis & Stathis, 2013; Qi et al., 2020). The selected influence criteria fit very well with the basic hydrological processes known in urban hydrology and cover the main morphological characteristics of the watersheds of the studied site.

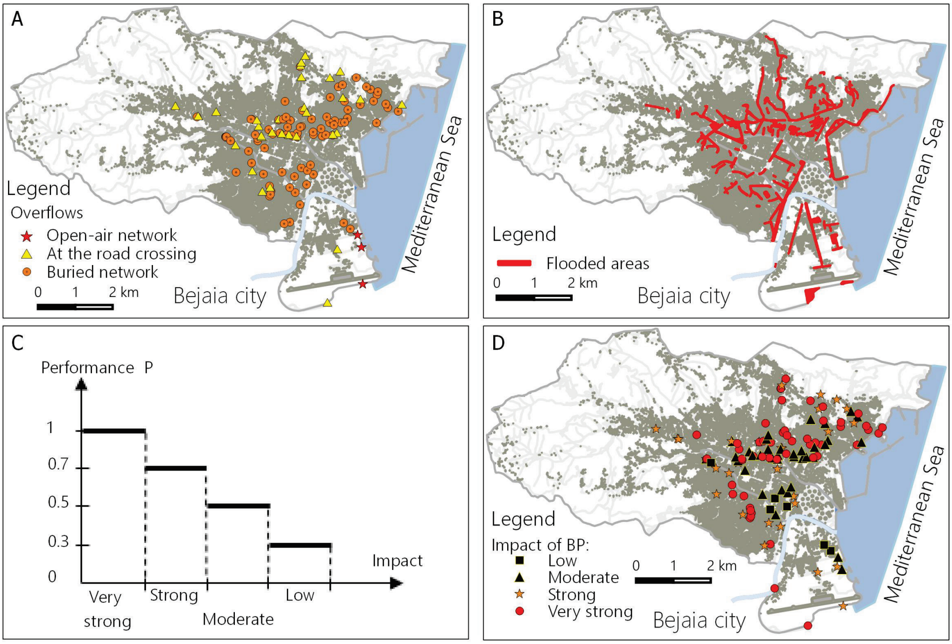

Figure 4. Classification of BPs based on expertise: Overflowing BPs (A), Flooded areas (B), BPs performance according to the importance of the impact diagnosed (C), and Mapping of BPs according to the importance of the impact diagnosed (D).

This analysis permitted to construct an evaluation grid consistent with the results of the diagnoses and the specificity of the study site. All criteria were assessed likewise in collaboration with field experts and engineers from the relevant departments. This approach type based on an expert survey is in common use (Boulomytis et al., 2019). To quantify the criteria, a performance scale from 0 to 1 was carried out. Depending on the magnitude of the impact or influence, we have defined five levels of performance: *strong*, *average*, and *low* for direct influence, and *vulnerable* and *not vulnerable* for indirect influence. We established a scale consistent with all the criteria (Table 1; Figure 5). For example, if the inundated surface (C_3) is important, we give it value 1 (which corresponds to Strong in Table 1; Figure 5).

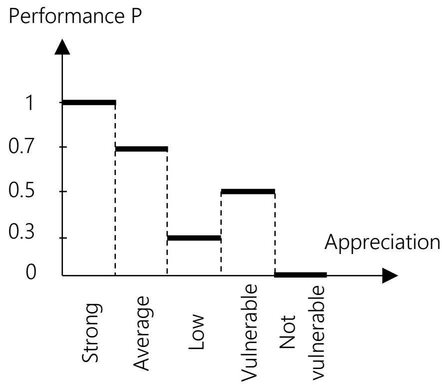

Figure 5. Adopted performance scale.

Table 1. Definition and evaluation scale of the selected influence and impact criteria

Type of criterion	Criteria			Description	Performance
Impact criteria	C_1: Traffic disruption		Unfrequented lane	Pedestrians and/or vehicles	Low
			Moderately frequented lane		Average
			Very frequented lane		Strong
	C_2: Sensitivity of the affected area	Presence of active structures	Strong or vital	Hospital, Station, Shopping center, Leisure and attraction center, University, Dense dwelling, etc.	Strong
			Average	School, moderately dense housing, small health center, etc.	Average
			Low	Residential or Suburban zone, small shops, etc.	Low
	C_3: Inundated surface		Important	Evaluated from Figure 4B (to scale)	Strong
			Average		Average
			Low		Low
	C_4 : Flood level		Important	≫ Sidewalk border	Strong
			Average	≳ Shoulder	Average
			Low	< Shoulder	Low
Influence criteria	Upstream watershed	C_5: Area (A)	High	A > Several ha	Strong
			Average	A = a few ares to a few ha	Average
			Low	A < a few ares	Low
		C_6: Average slope (S)	Strong	S > 5%	Strong
			Average	S = 2 to 5%	Average
			Low	S < 2%	Low
		C_7: Elongation ($E = L/\sqrt{A}$)	Strong	E > 2	Low
			Average	E = 2	Average
			Low	E < 2	Strong
		C_8 : Time of concentration (t_c)	Strong	Low S and Strong E	Low
			Average	Low S and Low E or high S and high E	Average
			Low	Strong S and Low E	Strong
		C_9: Waterproofing coefficient	High	> 80 %	Strong
			Average	40 to 80 %	Average
			Low	< 40 %	Low
	C_{10}: Observed failure—(Cause of flood)		Fouling	Total (Obturation)	Strong
				Partial	Average
			Undersizing		Average
			Other		Low
			None		Not vulnerable
	C_{11}: Upstream conduit		Open-conduit		Vulnerable
			Closed-conduit		Not vulnerable
	C_{12}: Conduit junction		Yes		Vulnerable
			No		Not vulnerable

Note. Performance rating scale: P = 1; 0.7; 0.3; 0.5 and 0 for Strong (or high); Average; Low; Vulnerable; Not vulnerable respectively (stronger is the impact, higher is the performance P with P = 0 to 1).

3.3 Evaluation of performances and classification of BPs

3.3.1 Evaluation of criteria—Performances

On Figure 6, when the performance of the BPs is evaluated considering a criterion, it is ranked in order of importance from 0 to 1 to show the different percentages of the BPs having the same performance (e.g., for C_1, 38%, 41%, and 21% of the BPs having the performances 0.3, 0.7, and 1 respectively).

Figure 6 illustrates the influence of the selected criteria (see Table 1) on the studied BPs. More than 50% of BPs have strong surfaces and slopes (criteria 5 and 6 with P = 1), and more than 40% have significant flooded surfaces (criterion 3 with P = 1). A low and medium concentration time (criterion 8, P = 1 and 0.7) characterizes more than 24 and 60% of the BPs respectively (i.e. an influence of more than 84% of the BPs). The other criteria (1 and 4) have a lesser but unimportant influence (P = 1 for 20 to 40% of the BPs and P = 0.7 for 20 to 45% of the BPs). This diagram will be used to identify the classes in the classification of BPs in Section 3.3.3.

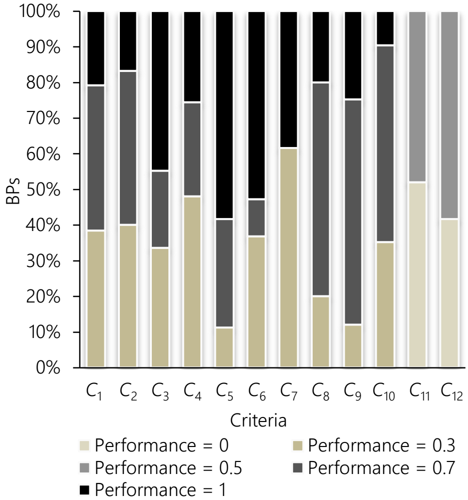

Figure 6. Performance by BPs.

3.3.2 Classification of BPs – Modeling

3.3.2.1 AHP method

The AHP method is divided into several steps as shown in the following list (Benzerra et al., 2012; Saaty, 2008):

- *Hierarchical structure of the problem*: It consists of prioritizing between criteria belonging to the same BP, according to the importance principle. Let C_1, C_2 . . . C_n be the set of criteria for which we are looking for the weighting coefficient. According to the prioritization principle, C_1 is more important than C_2 which is more important than C_{n-1}, which is more important than C_n. Finally, C_n is the least important indicator.
- *Criteria comparison matrix*: The decision matrices ($n \times n$) are composed of elements a_{ij}. The element a_{ij} represents the order of preference between indicator/criterion i and indicator/criterion j. The values of a_{ij} are assessed by pairwise comparison using the AHP scale (Equation 1). It goes from 1 to 9 where 1 implies there is no preference between two criteria and 9 means a criterion is absolutely preferred over another. We introduced judgments closer to reality on expert opinion (Benzerra et al., 2012; Chang et al., 2007):

$$a_{ij} = w_i / w_j;\ \ a_{ji} = 1/a_{ij}\ \text{ and }\ a_{ij} = 1 \quad (1)$$

$a_{ij} > 0$ being the importance intensity of C_i on C_j and w_i the weighting coefficient associated with C_i.

- *Determination of criteria weights*: This involves calculating the weighting coefficients vector $W = \{w_1 \ldots w_2 \ldots w_n\}$. To do this, we used MATLAB. Each coefficient w_i is obtained by the Equation 2:

$$W_i = \frac{1}{n} \sum_{i=1}^{n} \left(\frac{a_{il}}{\sum_{k=1}^{n} a_{kl}} \right) \quad (2)$$

with $\sum w_i = 1$. Subsequently, the weights of the criteria are expressed in weighted values.

- *Checking of results consistency*: AHP is used to calculate consistency index (*CI*) and then consistency ratio (*CR*) which allows checking the calculations made. It allows checking whether the scale values (1–9) assigned by the decision-maker are consistent or not. It provides a measure on the probability that the matrix is in a random pure state. Thus, AHP does not require decision-makers to be consistent, but rather provides a measure and helps reduce that inconsistency.
  We define the following two vectors:

$$\begin{bmatrix} \lambda'_1 \\ \cdots \\ \lambda'_i \\ \cdots \\ \lambda'_n \end{bmatrix} = \sum_{k=1}^{n} \left[w_k \times \begin{bmatrix} a_{1k} \\ \cdots \\ a_{ik} \\ \cdots \\ a_{nk} \end{bmatrix} \right] = \left[w_1 \times \begin{bmatrix} a_{11} \\ \cdots \\ a_{1i} \\ \cdots \\ a_{1n} \end{bmatrix} + \cdots + w_i \times \begin{bmatrix} a_{1i} \\ \cdots \\ a_{ii} \\ \cdots \\ a_{ni} \end{bmatrix} + \cdots + w_n \times \begin{bmatrix} a_{1n} \\ \cdots \\ a_{in} \\ \cdots \\ a_{nn} \end{bmatrix} \right] \quad (3)$$

and $\lambda_i = (\lambda'_i)/w_i$; $i = 1$ to n;

Then eigenvalue $$\lambda_{\max} = \frac{(\sum_{i=1}^{n} \lambda_i)}{n} \quad (4)$$

The consistency index *CI* shall then be:

$$CI = \frac{\lambda_{\max} - n}{n-1} \quad (5)$$

To calculate the consistency ratio *CR*, we divide *CI* by a value *RI* (randomized index) given as a function according to the criteria number *n*.

$$CR = \frac{CI}{RI} \quad (6)$$

Saaty (1980) and Benzerra et al. (2012) presents values of *RI* for different matrix size. The value of *RI* which corresponds to the size matrix of order 12 (n = 12) is 1.53.
The weight assignment is considered acceptable if *CR* is less than 0.1. Otherwise, the coefficients of the comparison matrix are inconsistent and the procedure must be applied again. The maximum vector λ_i' indicates the line in which there is a problem with a coefficient a_{ij}. If several coefficients are involved, the error becomes more difficult to locate.

- *Scores evaluation per BP*: The determination of the scores S_i of n BPs requires the aggregation of criteria. We opted for a complete aggregation for its clarity and simplicity (Bouyssou et al., 2006). It is the method of linear additions (also known as the weighted sum method) which is also one of the most used methods (Sahely et al., 2005). The Score *Si* (or overall score) of a BP_i is obtained by the following weighting relationship:

$$S_i = \sum_{i=j}^{n} w_j \; N_{ij} = w_1 \, N_{i1} + w_2 \, N_{i2} + \cdots + w_n \, N_{in} \tag{7}$$

and $N_{ij} = P_{ij}$, then:
S_i: Score of the BP_i (the greater S_i is, the more the BP has priority to be considered);
w_j: Weight assigned to classification criterion j of BP_i;
N_{ij}: Score assigned to BP_i with respect to criterion j; and
P_{ij}: Performance of BP_i with respect to criterion j.

3.3.2.2. FMEA method

FMEA was used for the management of failure risks of the sewerage system of Algiers (Benbachir et al., 2022; Cherrared, 2016). Using the FMEA method to classify the BPs, this is an estimate of a criticality index (I_c) of BP studied. Especially since in practice, we consider that an overflow is all the more important as its impact is great. Therefore, the FMEA method is simple and easy to adopt in our case study.

3.3.2.2.1. Assessment parameters

Three risk assessment parameters have been defined:

- "Risk" of overflow: it is defining the relevant criteria allowing to assess the risk of overflow. For example, a BP with higher performance (toward the overflow) than another BP is a sign that it will present a greater overflow risk.
- "Severity" of the overflow: we consider a recognized overflow situation and we try to estimate its gravity. This amounts to consider and quantify overflow's consequences. Otherwise, could this overflow cause damage to property and people? If so, what degree of severity can it be attributed to? The answer should necessarily be based more on the impact criteria than on the influence ones.
- A "Detectability time": this plays an important role in estimating the BP criticality. Each BP is assigned a detectability period depending on its location, the overflow impact, or its management system. For example, it is obvious an overflow on a busy road will be identified more quickly than on a road with little traffic.

3.3.2.2.2. Criticality index

Criticality index I_c of a BP can be assessed with the Equation 8 (Dyadem Press, 2003; Stamatis, 2003):

$$I_c = (N_m)_{Risk} \times (N_m)_{Severity} \times (N_m)_{Detectability\ time} \tag{8}$$

N_m is the average score assigned to each parameter:

$$N_m = \frac{\sum_{j=1}^{n} N_j}{N_{max}} \tag{9}$$

where N_j is a score given to criterion j of the considered parameter, *n* is the number of criteria, N_{max} is the sum of the max scores given to the criteria of each parameter.

Table 2. Scores of the selected criteria for FMEA method

Parameter	Criteria	Performance					N_{max}
		Not vulnerable	Low or short	Vulnerable	Average	Strong	
Risk	C_5 to C_9	—	0.3	0.5	0.7	1	7
	C_{10}	0	0.3	0.5	0.7	1	
	C_{11} and C_{12}	0	—	0.5	—	—	
Severity	C_1 to C_4	—	0.3	—	0.7	1	4
Detection	Fast (frequented place)	—	0.3	—	—	—	1
	Slightly fast (Uncrowded area)		—		0.7		

3.3.3. Studied BPs classes

To test the reliability of the methods used (AHP and FMEA), we compared the BPs modeled performance to that deduced from the survey and observation data. The criterion used to evaluate the observed performances is the "flooded area" (Figure 4B and 4D).

Logically, the larger a flooded area of a BP is, the higher the S score (AHP) and the criticality index (FMEA) will be. Figure 7 illustrates the results obtained. We used the Xlstat program to compare AHP and FMEA ranks on the twelve selected criteria and also to search for criteria grouping maximum of BPs. We focused on the ranks of the BPs and searched for a link between the parameters influence and the rank of each BP. In the first step, we plotted the pairwise cloud of the ranks of each BP to give a measure of the intensity and the linear direction relationship between two ranks (Figure 8A), then, to target BPs with the same characteristics (Figure 7) and for more precision in their final classification, we preferred to work by BPs classes.

4. Obtained results and discussion

According to our results, the two methods (AHP and FMEA) give results of BPs classification that are consistent with those observed in relation to flooded surfaces. In addition, Figure 7 shows that both AHP and FMEA give highly comparable ranking results.

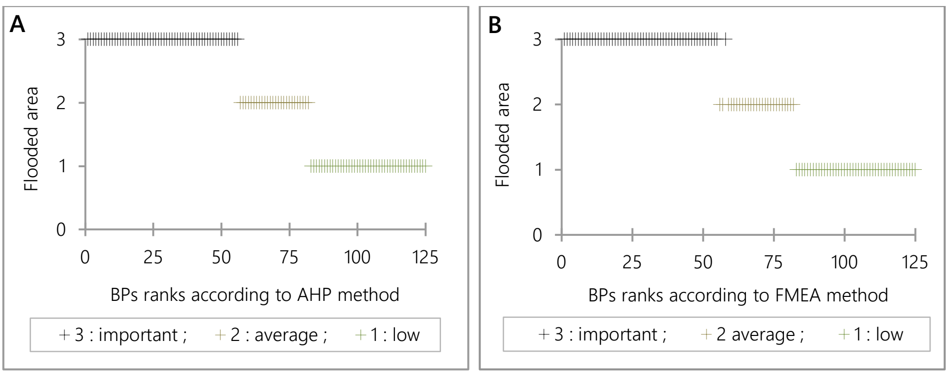

Figure 7. Comparison of observed and modeled BPs performance using AHP (A) and FMEA (B).

These classes were defined based on the observations illustrated in Figure 8:

- Class 1 (C_5, C_3): classes including BPs with criteria values 5 and 3 (surface and inundated surface criteria) with fixed performances values.
- Class 2 (C_5, C_6): classes including BPs with criteria values 5 and 6 (surface and slope of upstream catchment criteria) with fixed performances values.
- Class 3 (C_5, C_{11}): classes containing targeted surface BPs and upstream conduit performance values.

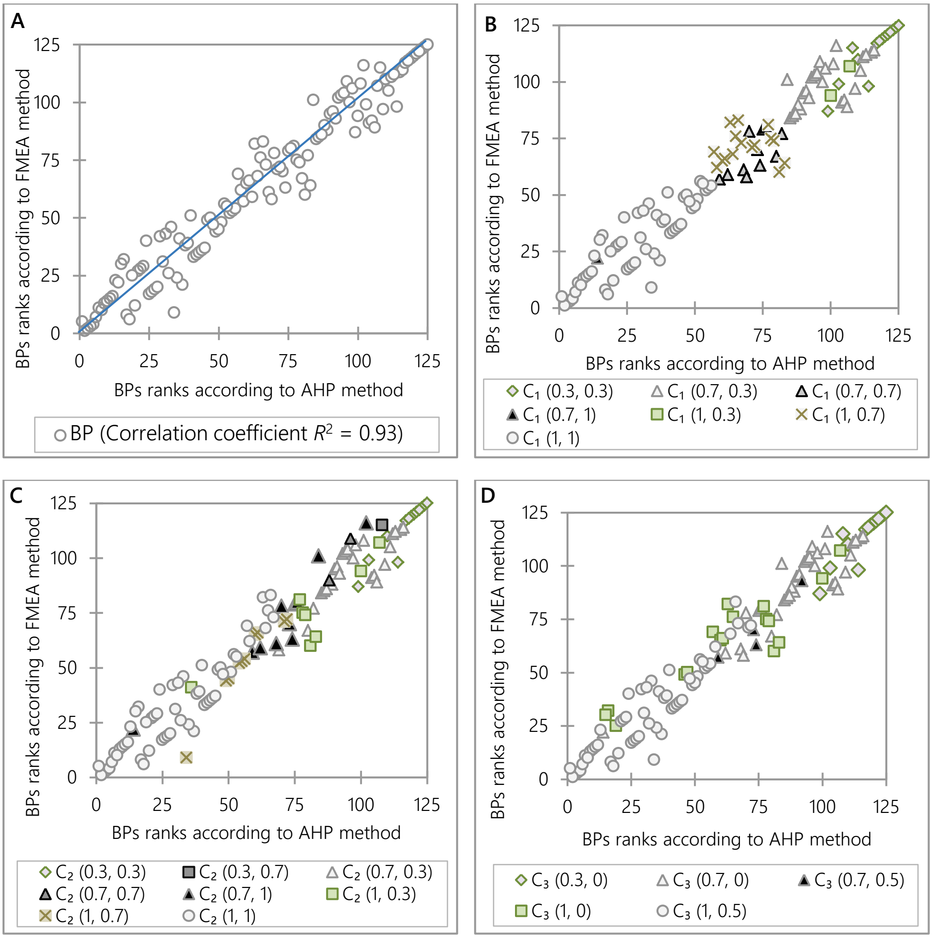

Figure 8. Results of multicriteria classification obtained per both methods.

Note. Panel A: Comparison of results of AHP and FMEA. Panel B: BPs of class 1 (surface and inundated surface performance values). Panel C: BPs of class 2 (surface and slope of upstream catchment performance values). Panel D: BPs of class 3 (surface and upstream conduit performance values).

Criteria performance values of C_3, C_5, C_6, and C_{11} are defined by Table 1 and Figure 5. For example: in Figure 8D, C_3 (1, 0.5) presents the class 3 (C_5, C_{11}) BPs of performances P = 1 and P = 0.5 respectively to criteria C_5 and C_{11}. Knowing the BPs performances with respect to criterion C_5 are P = 1; 0.7 and 0.3, and P = 0.5 and 0 are BPs performances with respect to C_{11}. So we have 6 possible cases, C_3 (1, 0.5), C_3 (1, 0), C_3 (0.7, 0.5), C_3 (0.7, 0), C_3 (0.3, 0.5), and C_3 (0.3, 0), but 5 in Figure 8D classes because no BP corresponds to class C_3 (0.3, 05).

Overflow causes analysis and BPs performance values allow to define priorities to classify the BPs into:

- Priority 1: BP to be managed immediately by remedying the problems causing the overflow (removal of gaps, upstream alternative technique, etc.) (40.8% of BPs);
- Priority 2: short-term action; BP to be managed within one to two years (26.4% of BPs);
- Priority 3: medium-term action (to be carried out in up to five years) (25.6% of BPs); and
- Priority 4: long-term action (7.2% of BPs).

The obtained BPs classification results are presented in Figure 9, which also shows that the BPs classified as priority 1 exceed one third (40.8%), then BPs are respectively priority 2 (26.4%) and 3 (25.6%). The rest is priority 4 (7.2%). Figure 9c allows them to be located and visualized. The important BPs are located in places with much higher slope influence (around the city). This map also allows managers to further refine intervention priorities by considering impact criteria such as "Traffic disruption" (criterion C_1) and "Sensitivity of the affected area" (criterion C_2; Table 1).

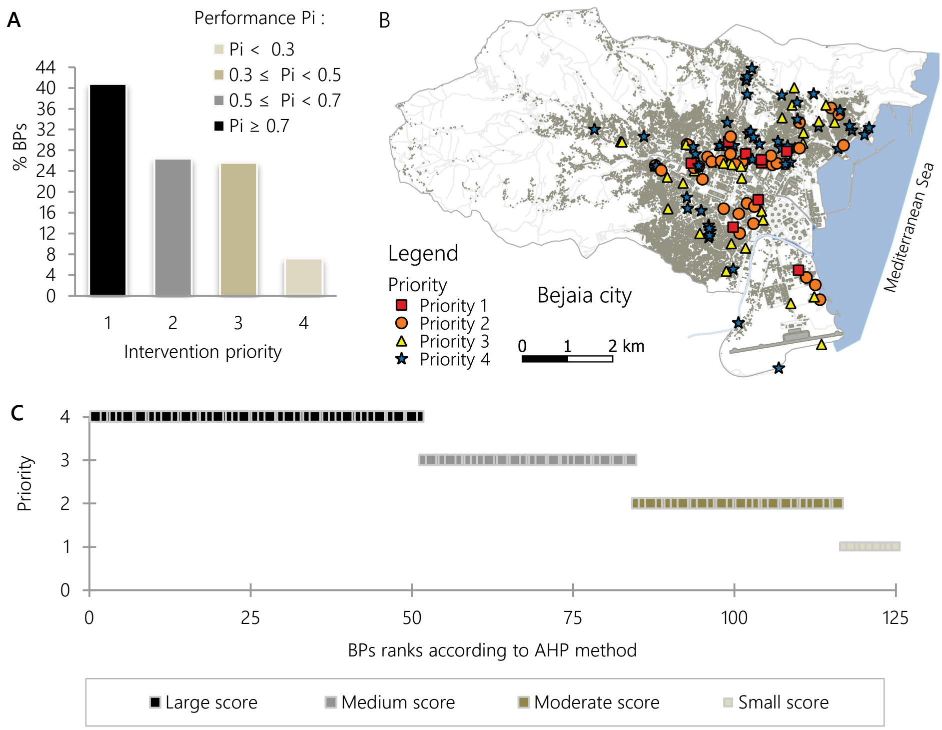

Figure 9. Classification (C) and mapping (B) of BPs in order of intervention priority (A).

These different graphs and results show, on the one hand, that the used criteria are reliable and sufficient, and on the other hand, AHP and FMEA methods give results that are similar and consistent with the diagnostic data and expertise. FMEA is a powerful risk assessment tool (Wang et al., 2018) and the obtained results show that it is adapted to this kind of study. The AHP represents a hierarchical analysis and validation tool in the field of sewer networks condition analysis to make the best management decisions. One of its most important limitations to mention is the fact that additional criteria can be taken into account and used if deemed necessary by stakeholders and decision-makers. However, in such a case, the AHP analysis must be redone completely, with new questionnaires and comparison matrices to reflect the relevant changes made to the model (Vladeanu & Matthews, 2019). The coupling of both methods was used on the Algiers network to manage the structural failures of sewerage collectors (Benbachir et al., 2020) and the results obtained are very encouraging.

5. Conclusion

The proposed methodology permitted to establish an overflows map occurred on Bejaia city's SDS and to rank black points (BPs) in importance order by applying AHP and FMEA methods. The approach is based on data observed and mapped during past inundations. The originality of the study and its innovative character lie in the used approach, which combines both the use of cartographic data from past inundations and multicriteria analysis methods such as AHP and FMEA. The reliability of the two methods used was tested by comparing them with the observed data using the "flooded surface" impact criterion (agreement between the classifications obtained by the observed data and by the used models, Figures 7 and 8). Both methods provided very interesting ranking results. AHP and FMEA seem to be more efficient, in this domain, particularly for the most overflowing BPs (with large flooded area; Figure 8B).

However, it is very important to have all the necessary data, particularly those based on surveys and field visits. On the other hand, the approach used in this study could present difficulties linked to the subjective description of certain evaluation criteria (such as the quantification of the vulnerability of an urban district to flooding through the impact criteria) and to the relative importance among the awarded scores. In our case, the fact of building an evaluation grid based on the impacts of past inundations (in collaboration with local experts) made it possible to overcome these difficulties.

In terms of management, the BPs were mapped in order of importance and priority of intervention (Figure 9C). This can serve as a practical and effective decision-making tool to intervene quickly and effectively to correct the failures causing the urban floods. Thus, it meets the needs of the manager, especially when the available means are insufficient as is the case in Bejaia. Poorly performing sewerage networks could benefit from relatively optimal maintenance planning, given the priorities are established according to the performance values with respect to overflows.

However, the used approach, strongly linked to the use of raw information and the construction of performance scales and evaluation of impact and influence criteria, requires continuous update of the database on the characteristics of watersheds and on the state and operation of the network. A decision support tool must be based on regular follow-up of the sewerage network (adequate diagnostics and surveys with the collection of objective information) and allowing a continuous multi-objective analysis of the SDS performance. Even though the methodology applied in this study is highly simple, yet it shows high accuracy, and can be used in other regions for overflows studying and mapping.

In perspective, it would be very interesting to combine the both methods. We believe that FMEA, coupled to the AHP method, would certainly provide more consistent and solid support in the final decision-making.

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