Development of an assessment tool for infrastructure asset management of urban drainage systems

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ABSTRACT

The present paper deals with the improvement of infrastructure asset management of urban drainage systems (UDS). A numerical tool for assessing the existing management procedures is proposed. It is based on a participatory methodology for the construction of a set of performance indicators. This methodology consists of two phases. The first concerns the identification of priority objectives, criteria and indicators related to the management of the UDS infrastructure. The second phase concerns the assessment of the global performance for each identified objective. Performance measurement scales are first defined for all the elements of the proposed methodology. Then, the Fuzzy Analytical Hierarchy Process (FAHP) is used for the weighting stage, and the Weighted Sum Method is used for the aggregation of indicators and criteria. To illustrate this methodology, a case study concerning Bejaia City in northern Algeria was carried out. Two priority objectives are identified for this case, they are divided into 6 criteria and 31 indicators. The results of the application of the developed tool highlighted some weaknesses that need improvements in the actual management procedure applied by the local sanitation services.

Key words | asset management, FAHP, performance indicators, performance scales, urban drainage systems

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HIGHLIGHTS

- A participatory methodology approach is proposed for the assessment of urban drainage management.
- The methodological approach is based on two phases.
- A set of decision elements are identified as objectives, criteria and indicators
- Performance scales are constructed for the decision elements
- The proposed methodology could be applied to developing countries.

INTRODUCTION

Urban drainage systems (UDS), like other public facilities, represent colossal investments for localities, and their management is a major concern, particularly for low-income countries (Cossio *et al.* 2020). Over recent years, managers of the Algerian National Sanitation Office (ONA) have been worrying about the degraded state of their urban drainage networks. This concern is compounded by complex situations that vary from one city to another according to their local specificities. Degradations often come as several failures such as collapse of collectors, leakage of wastewater, poor structural conditions of networks, etc. Also, these situations interact with various network characteristics like its total length, the diversity of materials composing its pipes, and its interaction with other public networks (drinking water, gas, electricity, etc.) as outlined by Bedjou *et al.* (2018). Other studies carried out in the same context, by Benzerra *et al.* (2012) and by Boukhari *et al.* (2017), have shown insufficient funding, obsolete regulation, absence of adequate structured methodology, and lack of data on the evolution of the structural quality of

doi: 10.2166/wst.2020.356

UDS. Moreover, the sanitation networks are buried: 'We do not see them'. All these aspects directly impact not only the level of knowledge of degradations over time, but also the degree and the speed of the stakeholders' reaction. As a result, ONA's managers found it very interesting to get an efficient tool that allows them to assess their management of drainage networks. The aim is to improve and to ensure continuity of service to users.

The management procedure should be developed within a long-term approach. It therefore must take into account the actual structural conditions of the network as well as the technical and financial constraints and their evolution. Accordingly, the present research is particularly interested in non-visitable networks with pipe diameters less than 800 mm.

Actually, the scientific challenges that are faced are linked to the construction of an evaluation tool that can answer all the questions associated with the local context. How to develop an evaluation tool that is not costly? How to use and exploit the limited available data? How to synthesise data of different natures? These questions given as examples are enough to show that the evaluation model to be developed must come from a participatory approach, between the different stakeholders, to promote its success. Therefore, we think it is best to: 'Dream big, start small. But most of all, start' as the author and motivational speaker Simon Sinek advises. In fact, various working meetings were held with managers of ONA to select their priority objectives based on the available technical and financial resources.

The use of assessment tools based on performance indicators can be beneficial to managers of UDS. They measure the quality of the service provided to users as well as the effectiveness and efficiency of the management company. Regarding the decision-making mechanism, they, among other things, help to: (a) identify the possible network failures to program their rehabilitation, (b) make feasible comparisons between the developed priority objectives, (c) facilitate benchmarking between the different management units of the country, (d) create some positive competition between management units, (e) develop a clear knowledge of the national political decision-making organisations, such as the Ministry of Water Resources, responsible for the allocation of the necessary budgets.

Over the past 30 years, several studies have been published in the field of water management assessment. Several authors (Cardoso *et al.* 2012; Silva *et al.* 2016) recommend using the approach based on objectives, criteria and performance indicators. Santos *et al.* (2019) conducted a literature review on the set of performance indicators used worldwide in the field of water service management. The authors reported that water services regulation organisations and agencies are the development precursors of evaluation tools by performance indicators. Among organisations, they cited: The International Water Association group (IWA), the American Water Works Association (AWWA), Office of Water Services (OfWAT). Other authors have focused their research on the structure of the network only. De la Fuente *et al.* (2016) and Nam *et al.* (2019) built a decision tree composed of a set of objectives, criteria and indicators to assess the structure of a network. They used the Analytical Hierarchy Process (AHP) method to determine the weight of each element of the decision tree. Some studies have preferred to use the notion of factors, such as Hawari *et al.* (2018) and Vladeanu & Matthews (2019). They introduced factors influencing the structural quality of the pipes. The weight of each factor is determined in the first reference by employing a combination of Fuzzy Analytical Network Process (FANP) and Monte Carlo methods, while the AHP method is chosen in the second reference. Daher *et al.* (2018) assessed, using the Analytical Network Process (ANP) method, the structural conditions of the pipes, joints and manholes.

At the national level, very few works have been devoted to this issue. Nevertheless, Benzerra *et al.* (2012) and Boukhari *et al.* (2017) have developed a hierarchical structure of objectives, criteria and indicators for the evaluation of the sustainable management of the sanitation service in Algeria. However, no work has dealt particularly with the structural aspect of UDS. The aim of this research is therefore to contribute to the assessment of the management quality of the UDS infrastructure. The drainage network of Bejaia City is taken as a case study; this city is located in the northeast of Algeria. The adopted methodological approach is based on two essential phases: the first phase is focused on the identification of objectives, criteria and indicators. The selection of the selected indicators takes into account the financial and the human resources available at the ONA unit of Bejaia. The second phase is concerned with the evaluation of the selected indicators. During this phase, the construction of performance scales for each indicator is necessary. Finally, performance notes are obtained for the agreed target objectives by using FAHP and Weighted Sum methods.

METHODOLOGICAL APPROACH

Assessment of asset management of UDS infrastructure is very complex due to the diversity of its structures and their underground and collective character. The choice of elements of the physical system to take into account depends on several parameters such as the definition of the priority objectives, the purpose of the evaluation, the data constraints and their cost. Consequently, the system studied herein includes the technical and political organisation managing the infrastructure, as well as structural elements: pipes, manholes and inlets.

As stated above, the methodological approach adopted in this paper followed two essential stages. In the first, indicators allowing the assessment of the quality management of the UDS infrastructure are identified. During this stage, it was necessary to make use of diverse specialists' opinions. It was also necessary to take into account the quality of the useful available data and the existing management strategies of the ONA agency. Indeed, the ONA's financial and human resources constituted a particular criterion in the selection of the selected indicators. Finally, this first stage resulted in retaining two objectives defined by six criteria, which in their turn are constituted by thirty-one (31) indicators.

The second step consisted of the construction of performance functions that define measures for the selected indicators. This resulted in a transformation of these initial measures into a performance score. Indeed, the aggregation and the weighting of the indicators led to the criteria performance rating. Then, in the same manner, the aggregation and the weighting of the criteria led to obtaining a single performance note for each defined objective. To carry out this assessment, a multi-criteria decision support approach, based on the performance indicators, was adopted. This approach consisted of the Fuzzy Analytical Hierarchy Process (FAHP) (Van Laarhoven & Pedrycz 1983). This powerful method made it possible to successfully assess the level of asset management of the network infrastructure on the basis of the priority objectives. Figure 1 shows a summary representation of the adopted methodological approach, with its two phases, and the details of the achieved tasks are given in the following sections.

Identification of the priority objectives

In the present work, the identification and the selection of the priority objectives, criteria and performance indicators are entirely based on a participatory approach. In fact, it is structured on a succession of stages that are similar to a process of filtering criteria and indicators.

The starting point was a broad consultation of literature in the field of this study, and the specific issue of the quality of UDS infrastructures. Some examples of references that are very helpful include (Matos et al. 2003; De la Fuente et al. 2016; Hawari et al. 2018). For the city of Bejaia, under consideration herein, the most useful sources are the database of the ONA agency as well as the diagnostic and rehabilitation studies carried out by their experts (ONA 2018). Then, the second stage concerned several participatory meetings and discussions organised between the ONA agency and the LRHAE laboratory. The various analyses and suggestions made it possible to finalise a list of objectives, criteria and performance indicators. Seven experts are consulted to this aim: Four from the ONA agency and three from Applied Hydraulics and Environment Research Laboratory (LRHAE). The team from ONA is composed of the Director of the Agency, the Head of the operation service, and two Senior Engineers in charge of the Bejaia urban drainage operation and rehabilitation. All these experts have from 10 to 15 years of experience in managing and maintaining UDS. The team from LRHAE is composed of researchers and advisors with PhD degrees in the field of asset management and performance assessment. The selection of decision elements (indicators, criteria and objectives), as well their prioritisation through preference matrices, were a result of an agreement between all the experts after several meetings. It has been decided to fix a shortlist that takes into account the functional requirements of UDS and the specific local context. It included the irregularly updated database and the limited material and financial capacities of ONA.

The last point consisted of an in-depth in-situ investigation. Particular interest was paid to the state of deterioration of the UDS infrastructure and to the available technical and financial potential of the ONA agency. This agency counts 121 staff members and its budget varies between 1.64 and 1.94 million dollars per year. Global information concerning all Algerian agencies and their projects are covered and diffused on the website of the national direction: 'https://ona-dz.org/'.

The final retained hierarchic scheme is shown in Figures 2 and 3. It contains two main objectives: one for the infrastructure management and the other for the network operation, together with the indicators and criteria used. It was found that the first objective is the most complex task, it requires four criteria to be satisfied. First of all, it is essential to enhance the knowledge of the asset by making indexes and inventories of structural components, to provide technical training and experience exchanging opportunities for the staff of the

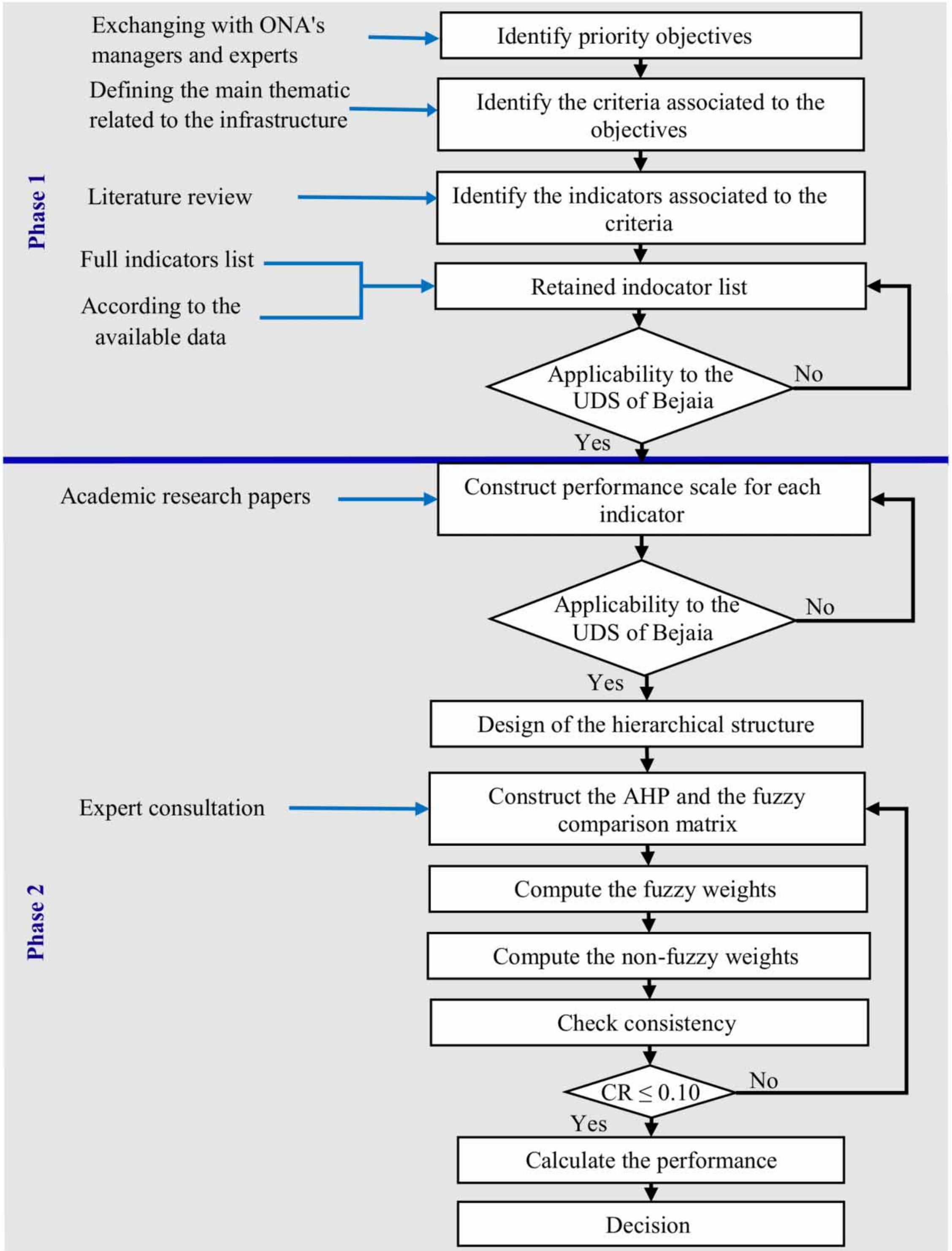

Figure 1 | Schematic description of methodological approach.

agency, to ensure availability of different means and tools for the regular inspections, etc. These are gathered in three indicators that are grouped in the first criterion. The second criterion is related to maintaining good structural and functional conditions of the drainage system.

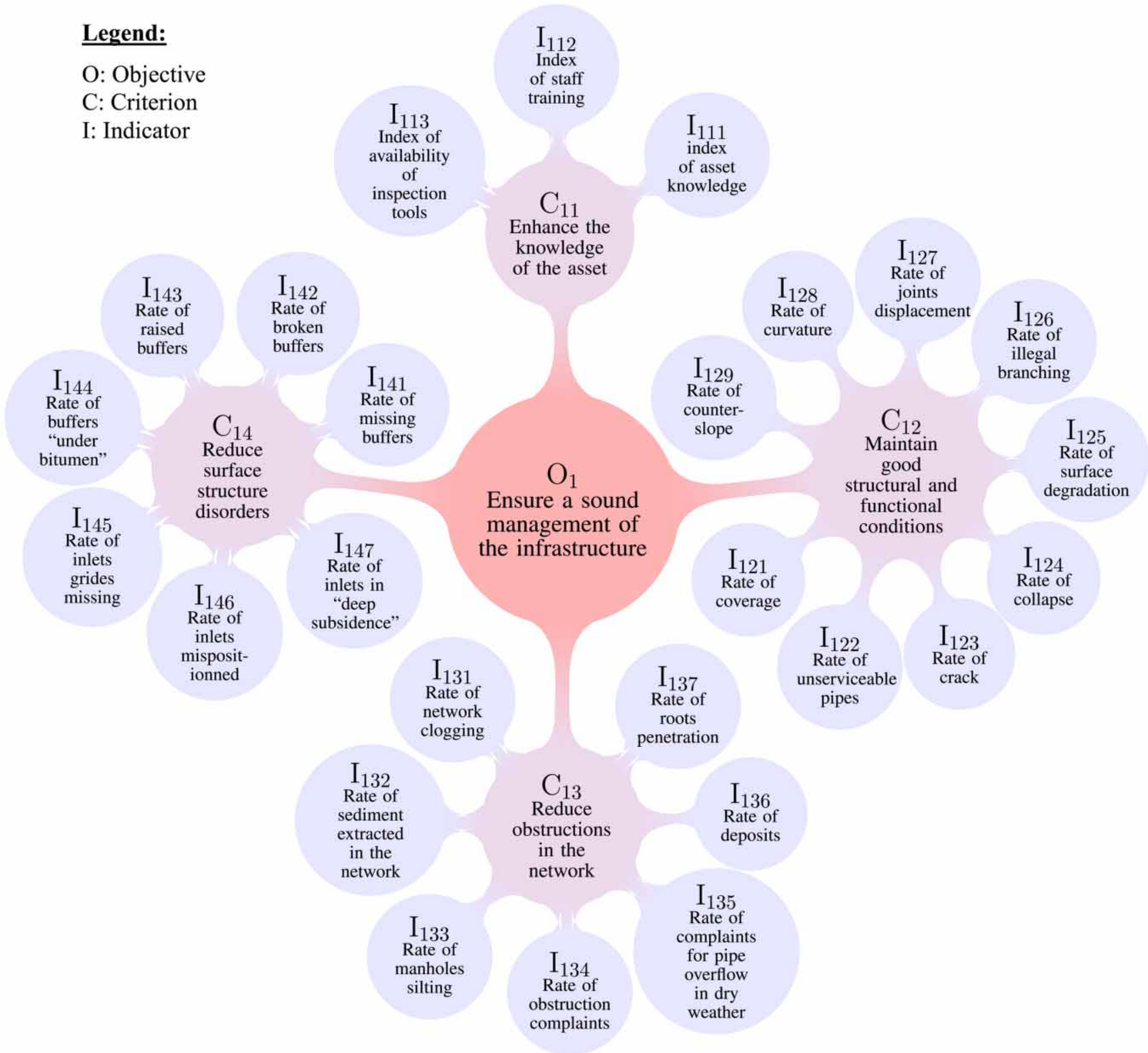

Figure 2 | Hierarchical scheme of objective O_1.

To fit with it, eight indicators are found to be convenient to adequately measure different rates of degradations or deterioration of structural elements, some undesirable aspects, interruption in functionality, and so on. In the third criterion, aspects are grouped that cause or increase the risk of obstruction in the network pipes. To reduce this risk, seven indicators are identified which may give reliable estimations of sediment inlet sources, transport and deposits within pipes. The last criterion concerns surface disorders; it consists of seven indicators assessing the technical conditions of the network inlets and buffers.

The second selected objective which should be reached to obtain a more in-depth assessment of the asset management of UDS infrastructure is to ensure efficient operation of the network. Two criteria are found essential for this reason. The first one concerns the quality of the continuous maintenance of the infrastructure provided by the ONA agency for the locality of Bejaia. Three indicators are defined for this criterion: rate of black spots, rate of preventive curing, and rate of restorative curing. These last two indicators concern surface elements of the network. The second criterion deals with rehabilitation actions, it gathers two indicators giving the rates of repaired pipes and the rate of replaced ones. As mentioned above, the performance assessment of the two objectives requires the construction of performance scales for each indicator. These functions are built according to the experts' recommendations. Then, the

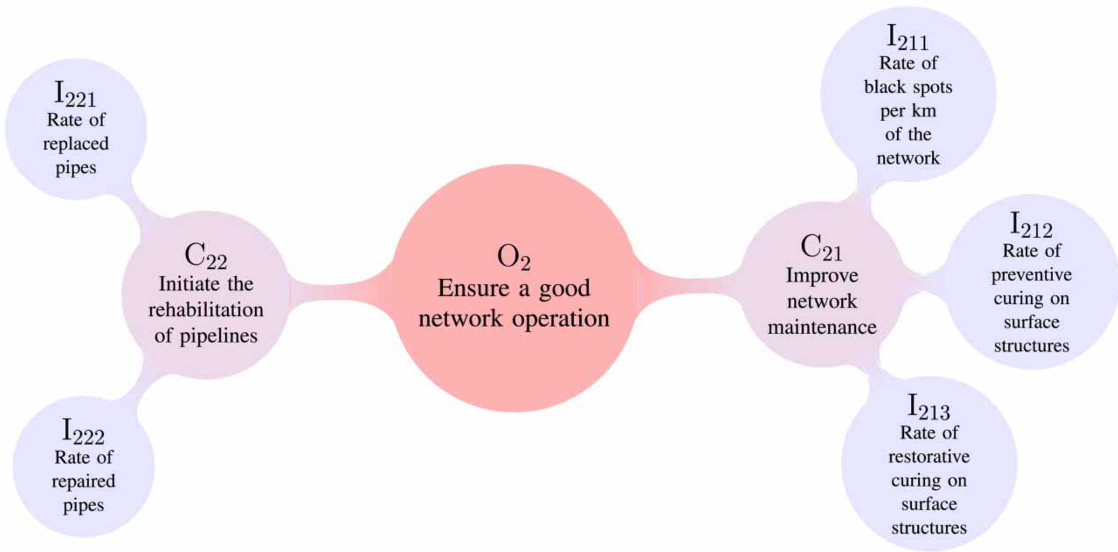

Figure 3 | Hierarchical scheme of objective O_2.

weighted sum and FAHP are used for the aggregation and weights calculation.

Performance scale

As with the definition of criteria and indicators, the construction of the performance scales required several discussions and meetings with the managers of the ONA agency. During the development of these scales, particular attention was paid to formulating, as rigorously as possible, the bounds of the performance levels. The performance measurement is achieved by mapping the indicator value onto a scale. The value of this performance is finite, quantitative and limited between 0 and 1, representing the worst to the best performance respectively. This range of variation is pertinent, it not only makes it easy to make a detailed distinction of the evolution of performance, but also fits well with the usage of AHP method. As an example, the performance function of the deposit rate indicator (I_{136}) is given in Figure 4. This indicator is given by the ratio of the number of pipes where deposits are observed on the total number of the examined pipes. The scaling assumes that when the deposit rate is less than or equal to 15%, the equivalent performance is between 0.5 and 1.0, but if the percentage exceeds the threshold of 35%, the performance is, in this case, zero. This operation is repeated for all indicators and criteria, but for the sake of brevity, the obtained performance functions are not plotted here. Nevertheless, the performance scale adopted for the two priority objectives is reported in Table 1; they will be used later.

Figure 4 | Example of performance function: Indicator I_{136} 'rate of deposits'.

Table 1 | Performance evaluation adopted for the two priority objectives

Range values	0.00–0.25	0.25–0.50	0.50–0.75	0.75–1.00
Quality	Bad	Weak	Good	Very good

Weights calculation

The weights of the developed indicators and criteria (Figures 2 and 3) were calculated on the basis of preference matrices, also called decision matrices. For this purpose, the FAHP method introduced by Van Laarhoven & Pedrycz (1983) is applied. This method is an extension of the AHP method initiated by Saaty (1980) which is based on pairwise comparisons of judgments. It integrates the importance of the criteria and the indicators into one overall score for the objective (Benzerra *et al.* 2012; Kessili & Benmamar 2016). Consequently, a prioritisation of each element of the decision from the least important to the most important was chosen. Thus, an entry in a decision matrix corresponds to a numerical note, defined in Table 2, which represents the degree of importance of one element compared to another. The numerical score is then fuzzified according to Khashei-Siuki *et al.* (2020). For instance, the values and their corresponding fuzzy numbers of the preference matrix of the three indicators related to criterion C_{11}: Enhance the knowledge of the asset, are given in Table 3.

From the fuzzy decision matrices, geometric mean values are computed for the elements (indicators, criteria) following the procedure proposed by Buckley (1985). These geometric means are then used to evaluate fuzzified weights, which are translated to non-fuzzy values by taking their centres of areas.

A geometric mean $\tilde{r}_i$ of an element i is determined using the following equation:

$$\tilde{r}_i = (\tilde{a}_{i1} \otimes \ldots \otimes \tilde{a}_{ij} \otimes \ldots \otimes \tilde{a}_{in})^{1/n} \qquad (1)$$

where $\tilde{a}_{ij}$ is the fuzzy comparison value of element i to element j, and n is the matrix size. The product rule between

Table 2 | Importance scale used for pairwise comparisons (Khashei-Siuki *et al.* 2020)

Linguistic variable	**Numerical score**	**Fuzzy number**	**Reciprocal fuzzy number**
Extremely strong	9	(9, 9, 9)	(1/9, 1/9, 1/9)
Intermediate	8	(7, 8, 9)	(1/9, 1/8, 1/7)
Very strong	7	(6, 7, 8)	(1/8, 1/7, 1/6)
Intermediate	6	(5, 6, 7)	(1/7, 1/6, 1/5)
Strong	5	(4, 5, 6)	(1/6, 1/5, 1/4)
Intermediate	4	(3, 4, 5)	(1/5, 1/4, 1/3)
Moderately strong	3	(2, 3, 4)	(1/4, 1/3, 1/2)
Intermediate	2	(1, 2, 3)	(1/3, 1/2, 1)
Equally strong	1	(1, 1, 1)	(1, 1, 1)

Table 3 | Preference matrix constructed for indicators related to criterion C_{11}

	Numerical score			**Fuzzy numbers**		
	I_{111}	**I_{112}**	**I_{113}**	**I_{111}**	**I_{112}**	**I_{113}**
I_{111}	1	1/4	1/5	(1,1,1)	(1/5,1/4,1/3)	(1/6,1/5,1/4)
I_{112}	4	1	1/2	(3,4,5)	(1,1,1)	(1/3,1/2,1)
I_{113}	5	2	1	(4,5,6)	(1,2,3)	(1,1,1)

I_{111}: Index of asset knowledge, I_{112}: Index of staff training, I_{113}: Index of availability of inspection tools.

two fuzzy numbers $\tilde{a} = (l_1, m_1, n_1)$ and $\tilde{b} = (l_2, m_2, n_2)$ is defined by

$\tilde{a} \otimes \tilde{b} = (l_1 l_2, m_1 m_2, n_1 n_2)$ with $l_1 \le m_1 \le n_1$, $l_2 \le m_2 \le n_2$.

The expression of the fuzzy weight of an element i is:

$$\tilde{w}_i = \tilde{r}_i \otimes (\tilde{r}_1 \oplus \ldots \oplus \tilde{r}_i \oplus \ldots \tilde{r}_n)^{-1} \qquad (2)$$

where the sum rule applies as: $\tilde{a} \oplus \tilde{b} = (l_1 + l_2, m_1 + m_2, n_1 + n_2)$, and the inverse of a fuzzy number is: $(\tilde{a})^{-1} = (1/n_1, 1/m_1, 1/l_1)$.

The defuzzification of $\tilde{w}_i$ gives the normalised (non-fuzzy) weights

$$w_i = A_i / \sum_{i=1}^{n} A_i \qquad (3)$$

where A_i is the arithmetic mean of the three components of the fuzzy weight $\tilde{w}_i$. A_i is also called the Center of Area. Application of this procedure to the decision matrix in Table 3 leads to the fuzzy and non-fuzzy weights of the three indicators related to the criterion C_{11}: Enhance the knowledge of the asset, as reported in Table 4.

As the weights calculations are based on decision matrices, they need to be checked for judgment consistency. A consistency ratio CR is determined to each weight; if it is found that $CR < 0.1$ then the decision matrix used for that computed weight is considered consistent enough. Otherwise, the experts are invited to revise their judgments to improve the consistency. The ratio is given by $CR = CI/RI$, where RI is a random index, as shown in Table 5, and $CI = (\lambda_{max} - n)/(n - 1)$. λ_{max} is denoted as the eigenvalue, it is evaluated from the arithmetic mean of the

Table 4 | The fuzzy and non-fuzzy weights of indicators related to criterion C_{11}

	Geometric mean ($\tilde{r}_i$)	**Fuzzy weight ($\tilde{w}_i$)**	**Non-fuzzy weight (w_i)**
I_{111}	(0.322, 0.368, 0.437)	(0.068, 0.097, 0.150)	0.097
I_{112}	(1.000, 1.260, 1.710)	(0.210, 0.333, 0.588)	0.348
I_{113}	(1.587, 2.154, 2.621)	(0.333, 0.570, 0.901)	0.555
Sum			1

Table 5 | Random Index (RI) (Benzerra et al. 2012)

n	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0	0	0.52	0.89	1.11	1.25	1.35	1.40	1.45	1.49	1.52	1.54	1.56	1.58	1.59

components u of the vector u defined by:

$$u_i = \sum_{i=1}^{n} M_{ij} w_j / w_i \quad (4)$$

where M_{ij} is the non fuzzy decision matrix used to compute the set of n weights w_i ($i = 1 \ldots n$).

After obtaining the performance scores and weights of lower hierarchical level elements, a weighted sum method is used for aggregation to obtain performance notes of higher hierarchical level elements. The expressions used for this purpose are:

$$P\ (\mathrm{C}_{kj}) = \sum_{i=1}^{n_i} P(\mathrm{I}_{kji}) w_i\ ;\ P\ (\mathrm{O}_k) = \sum_{j=1}^{n_j} P(\mathrm{C}_{kj}) w_j \quad (5)$$

where $P(\mathrm{I}_{kji}), P(\mathrm{C}_{kj})$ and $P(\mathrm{O}_k)$ denote the performance notes of the indicators, the criteria and the objectives, respectively. n_i is the number of indicators related to a criterion C_{kj}, and n_j is the number of criteria of the objective O_k, as they are defined in Figures 1 and 2.

APPLICATION OF THE ASSESSMENT TOOL

The proposed methodology is applied to the UDS of Bejaia City, Algeria. The city has 185,000 inhabitants and a surface area of 120.22 km^2. Due to topographic conditions, Bejaia is mainly expanding towards the east and towards the south. Actually, the main activities of its population consist principally in trade and industry. In fact, Bejaia contains a large industrial area and several tourist sites. Regarding the climate, it is mild, of the Mediterranean type, with wet winters and hot summers. The average annual temperature is 23 °C and the average annual rainfall is around 874 mm (ONA 2018).

Figure 5 shows a map of Bejaia and its UDS as reported from ONA internal report. The total length of the UDS is 312 km, represented by four colours on the map. Pipes subjected to pedestrian and video periscopic inspections are represented by red and green lines, respectively. These inspections are the two main techniques that are used during the diagnosis carried out by the SCE French Group and the ONA unit of Bejaia. Pipes not needing inspection are represented by grey lines, and those that are not inspected are represented by black lines.

It has been noted that 99.4% of the network operates in gravity mode, and is of unitary type and of circular shape. Approximately 88.32% of the network pipes is aged but without precision about its age, 8.67% was constructed before 1996, 1.78% between 1997 and 1999, and 1.23% from 2000 to now. The number of inlets is 5,010 and 9,787 manholes have been counted. Several anomalies have been recorded, which are summarised as follows: grates of inlets missing, inlets mispositioned and inlets in deep subsidence. The network is thus poorly maintained and presents several black spots; it needs sustainable measures. Concerning its hydrological capacities, in parallel to the buried drainage pipes, Bejaia watershed is equipped with several free surface open channels capable of evacuating exceptional flow discharges. However, there still remain mainly three zones of network overflowing, where flooding occurs practically each year.

Table 6 represents the average annual values of the constructed indicators used in the performance assessment of the UDS.

RESULTS AND DISCUSSION

In this section, the performance assessment of the two identified objectives «O_1: Ensure a good management of the infrastructure» and «O_2: Ensure a good network exploitation» was performed during the year 2018. The performance scales constructed for the indicators lead to the performance scores plotted in Figure 6. Results of the FAHP method applied for the determination of the weight for each element are shown in Tables 7 and 8. The judgement consistency ratios for all decision matrices are reported in Table 9. They show that the preference judgements are thus acceptable. The performance score of each criterion is obtained by aggregating the indicator performances displayed in Figure 7 together with the performance of the two priority objectives.

According to these results, good quality performance was obtained for the objective O_1 'Ensure a good

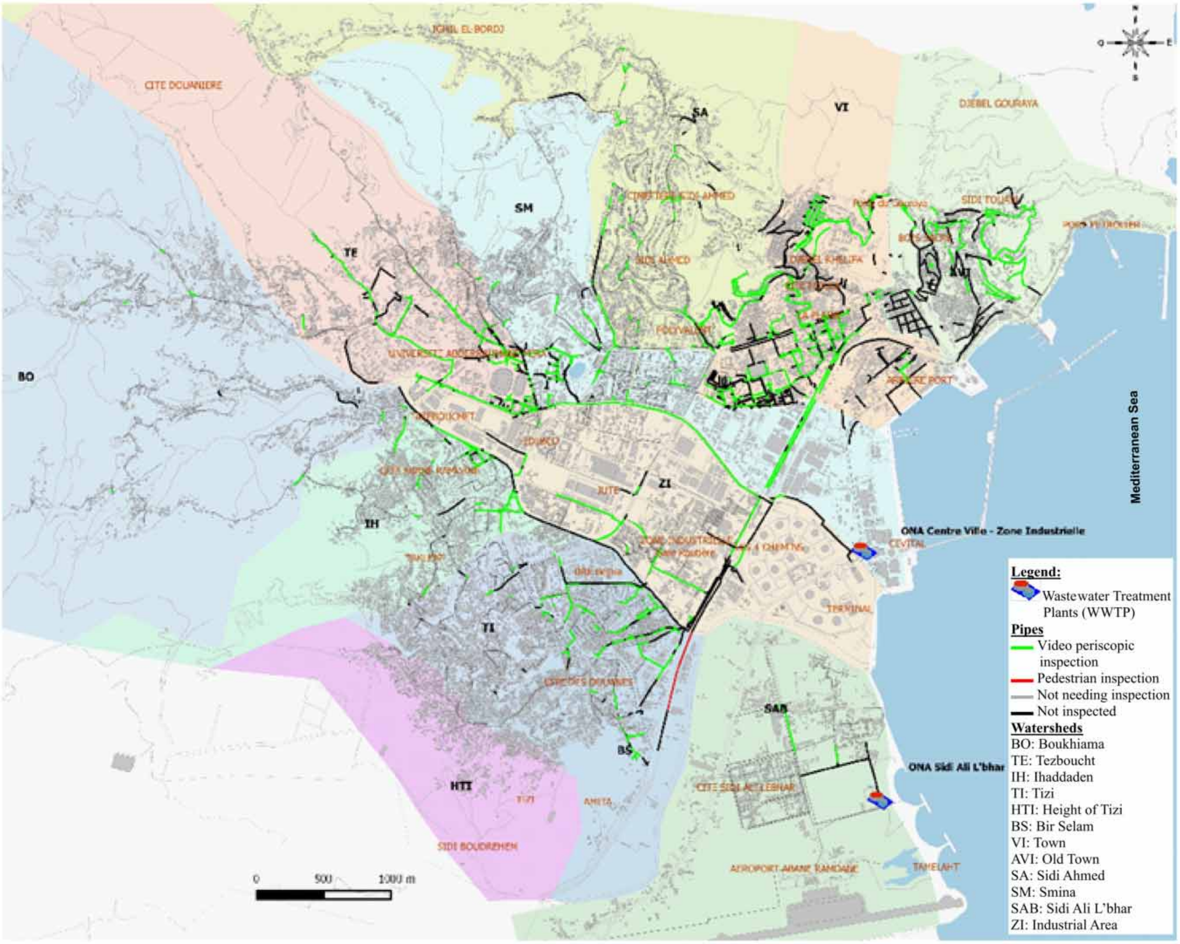

Figure 5 | General UDS Map of Bejaia City (ONA 2018). The full colour version of this figure is available in the online version of this paper, at http://dx.doi.org/10.2166/wst.2020.356.

Table 6 | Annual values [(*)] of the identified indicators (ONA 2018)

Indicator	Value	Indicator	Value	Indicator	Value	Indicator	Value
I_{111}	50.00	I_{126}	06.51	I_{135}	41.90	I_{146}	00.78
I_{112}	20.00	I_{127}	09.83	I_{136}	33.32	I_{147}	01.20
I_{113}	51.25	I_{128}	23.69	I_{137}	00.66		
I_{121}	83.00	I_{129}	00.41	I_{141}	00.81	I_{211}	21.00
I_{122}	02.41	I_{131}	11.00	I_{142}	02.77	I_{212}	04.63
I_{123}	04.69	I_{132}	29.20	I_{143}	07.69	I_{213}	31.64
I_{124}	01.95	I_{133}	08.40	I_{144}	12.90	I_{221}	01.60
I_{125}	18.92	I_{134}	75.59	I_{145}	02.19	I_{222}	00.96

[(*)] units: $[I_{113}]$ = hours/employees/year, $[I_{132}] = m^3/km$, $[I_{211}]$ = Number of points/km/year, others in [%]. (Refer to Figures 2 and 3 for descriptions of the indicators.)

management of the infrastructure' ($P(O_1) = 0.653$). However, attention must be paid to the interpretation of the performance at this hierarchical level, it can only provide an overall view of the management performance. Indeed, analysis of indicator performances may give more details about possible failures and can guide managers to act in

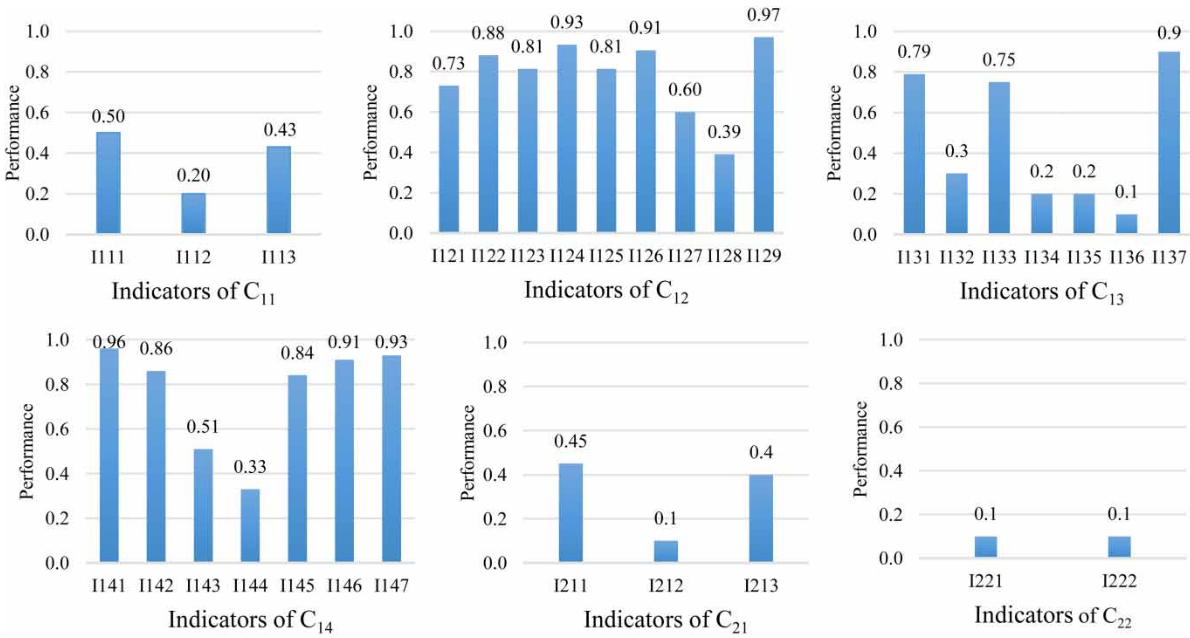

Figure 6 | Performance of indicators related to the two objectives.

Table 7 | The weights of 31 indicators obtained by FAHP

Indicator	Weight	Indicator	Weight	Indicator	Weight	Indicator	Weight
I_{111}	0.098	I_{126}	0.124	I_{135}	0.265	I_{146}	0.047
I_{112}	0.348	I_{127}	0.114	I_{136}	0.047	I_{147}	0.084
I_{113}	0.553	I_{128}	0.173	I_{137}	0.058		
I_{121}	0.017	I_{129}	0.070	I_{141}	0.217	I_{211}	0.186
I_{122}	0.038	I_{131}	0.127	I_{142}	0.233	I_{212}	0.379
I_{123}	0.267	I_{132}	0.117	I_{143}	0.092	I_{213}	0.435
I_{124}	0.051	I_{133}	0.074	I_{144}	0.141	I_{221}	0.743
I_{125}	0.146	I_{134}	0.313	I_{145}	0.185	I_{222}	0.257

order to improve the overall performance. As can be seen in Figure 6, various indicators (I_{112}, I_{113}, I_{128}, I_{132}, I_{134}, I_{135}, I_{136} and I_{144}) present performances lower than 0.5. This is due to the fact that the management of these indicators requires more financial and material means.

In contrast to objective O_1, weak quality performance was obtained for the second objective O_2 'Ensure a good network operation' ($P(O_2) = 0.140$). Analysis of the five indicators associated with this objective indicates that they, all of them, are of low quality.

Indeed, three of these indicators (I_{212}, I_{221} and I_{222}) obtained a performance note of 0.1, as shown in Figure 6. This result reveals: (i) the absence of coordination and communication between the network owner (Popular Communal Assembly of Bejaia) and the network manager (ONA); (ii) the disparity of actions between all the stakeholders; (iii) the lack of means for sound operation of the network. Besides this insufficiency, the two remaining indicators, I_{211} and I_{213}, display an acceptable performance great or equal to 0.4.

Table 8 | The weights of criteria obtained by FAHP

Criteria	C_{11}	C_{12}	C_{13}	C_{14}	C_{21}	C_{22}
Weights	0.077	0.143	0.214	0.566	0.203	0.797

Table 9 | Consistency ratios for the decision matrices of criteria and objectives

Decision element	C_{11}	C_{12}	C_{13}	C_{14}	C_{21}	C_{22}	O_1	O_2
Matrix size (*n*)	3	9	7	7	3	2	4	2
Eigenvalue (λ_{max})	3.027	9.696	7.444	7.444	3.025	2	4.158	2
Consistency Index (*CI*)	0.014	0.087	0.074	0.074	0.012	0	0.053	0
Consistency Ratio (*CR*)	0.023	0.060	0.056	0.056	0.021	0	0.058	0

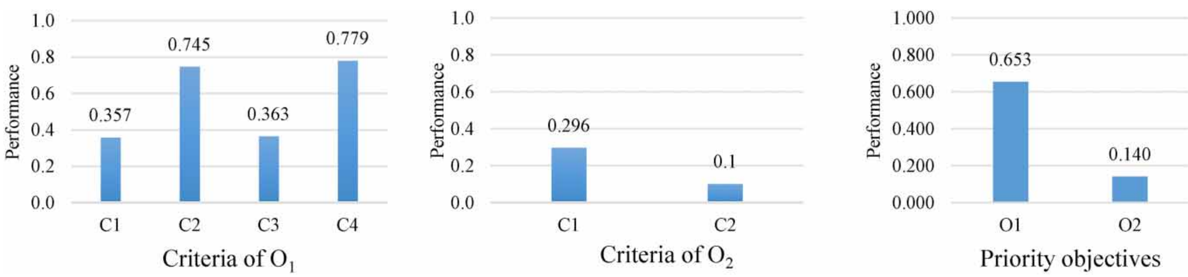

Figure 7 | Performance of the defined criteria and objectives.

CONCLUSION

The objective of this paper is to develop an assessment tool for infrastructure asset management of urban drainage systems. The methodology is illustrated through application to the case of Bejaia City. It aims to help ONA's managers to undertake the best actions for better governance decisions. Therefore, the methodology adopted is based completely on a participatory approach. Indeed, with the help of experts consulted, two priority objectives were selected: (i) Ensure a good management of the infrastructure and (ii) Ensure a good network exploitation. These two objectives cover six criteria, which are defined by a set of 31 indicators constructed taking into account the functional requirements of a UDS and the specific local context. The management assessment methodology developed in the present work was based on performance scales that were built for all defined indicators, criteria and objectives. Performance of the decision elements was determined by using the FAHP and weighted sum methods.

The obtained results showed a good performance for the first objective but several of its indicators displayed a poor performance. Also, a mediocre performance was found for the second objective, as evidence of the degree of divergence in the actions of stakeholders. Gathering these actors for health, economic and environmental partnership thus becomes an urgent priority. The performance indicators used in this study can provide interesting information to the managers of Algerian Sanitation Service. Its exploitation will allow the ONA to better act on the failures of UDS and increase its lifetime. Due to missing data and insufficient funding, we have been led to construct performance indicators based especially on the means available. Actually, the tool is in the process of being applied by ONA, the experience feedback will eventually bring elements for adjustment and improvement. It would thus be interesting to organise national meetings between the different units of ONA, in order to produce a common panel of indicators, criteria and objectives, accompanied by their performance scales. Only then, the principle of benchmarking could be used to encourage managers to perform better.

ACKNOWLEDGEMENTS

The authors are thankful to all the staff of the ONA agency of Bejaia for their precious advices, for the multiple working sessions and for providing the necessary database and the internal reports for conducting this work.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

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First received 8 June 2020; accepted in revised form 20 July 2020. Available online 31 July 2020