Algerian urban sewer systems durability – Study of the functional aspect of Jijel town's system

Durabilité des systèmes d'assainissement algériens Etude de l'aspect fonctionnel du système de la ville de Jijel

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ABSTRACT

This work enters within the framework of the elaboration of an evaluation methodology of the Algerian sewer system's sustainability. Criteria and performance indicators were elaborated and defined on the basis of specific information. A methodology to evaluate the system's performances was elaborated and digitized. The study deals with the functional aspect of sewer systems, objective retained out of seven sustainability objectives elaborated on the basis of problems met in Algerian sewer systems (Cherrared M. et al, 2007). A case study was carried out on the urban sewer system of Jijel (East of Algeria). The system's performances were evaluated per criterion and selected indicators (using the principle of the weighting of performance indicators). The methodology used is based on the exploitation (by various methods) of the data measured on site and methods assessing the indicators and performances defined within the framework of the study. The developed tool has a great flexibility and provides a prototype of dashboard for monitoring the performance of Algerian urban sewer systems. The exploitation of the case of Jijel shows on the one hand, the opportunity to complete the missing information by using specific ratios and on the other hand, the limits of methods based on the weighting of performance indicators.

RÉSUMÉ

Ce travail entre dans le cadre de la mise en place d'une méthodologie d'évaluation de la durabilité des systèmes d'assainissement (SA) urbains algériens. Des critères et des indicateurs de performance ont été construits et définis sur la base d'informations spécifiques. Une méthodologie d'évaluation des performances du système a été élaborée et numérisée pour construire un tableau de bord prototype. L'étude traite de l'aspect fonctionnel des SA, objectif retenu sur sept objectifs de durabilité définis sur la base de la problématique des SA algériens (Cherrared M. et al, 2007). Une étude de cas a été effectuée sur le SA de la ville de Jijel (Est algérien). Les performances du SA ont été évaluées par critère et par indicateur retenu (par le principe de l'agrégation et de la pondération). La méthodologie utilisée est basée sur l'exploitation (par différentes méthodes) des données mesurées sur site et sur des méthodes de calcul des indicateurs et des performances définies dans le cadre de l'étude. L'outil développé présente une grande souplesse d'utilisation et offre un prototype de tableau de bord pour le contrôle des performances des SA algériens. L'exploitation du cas de Jijel montre d'une part, la possibilité de compléter l'information manquante par l'utilisation de ratios spécifiques et d'autre part, les limites des méthodes basées sur la pondération des indicateurs de performances.

KEY WORDS

Algerian case, performance indicator, sewer system. sustainable development.

1 INTRODUCTION

The sustainable water management and the conception of sewer systems able to meet aims associated with the sustainable development policy are undoubtedly one of the fundamental urban questions at the present time (Cherqui F., 2005 ; Chocat B. & al, 2007 ; Granger D. & al, 2008 ; Guerin-Shneider L. & Nakhla M., 2003 ; Martin P. & al, 2001 ; Matos R. & al, 2003). To obtain a sewer system which limits the negative impacts on the environment, which limits the energy consumption, which protects the users and the personnel, which is able to provide a powerful service on the long run and which mobilizes multiple competences. In Algeria, managers of the sewer systems must face several realities. For example, the physical degradation of infrastructures due to ageing or defect of maintenance and the pollution of natural environments by discharges coming from urban sewer networks (rainwater and wastewater) which starts to become very worrying. The undertaken work aims to develop a powerful "dashboard" making it possible to evaluate the durability of the Algerian sewer systems. This article presents the elaborated and applied methodology, a short description of the computer tools carried out and used, and an application of the functional aspect to the sewer system of Jijel City.

2 METHODOLOGY

2.1 Methodological Flow Chart

The evaluation methodology of the performance is characterized by two stages. The first is the identification and construction of performance indicators; inspired from the problems in the Algerian sewer systems and the actual position of knowledge as regards sustainable development of these systems (CATE, 2004; Cherrared M. et al, 2007; CNES, 2005). The second phase consists in evaluating system performances (figure 1); it is based on the evaluation of performance indicators (table 1) and of performances of criteria by their aggregation.

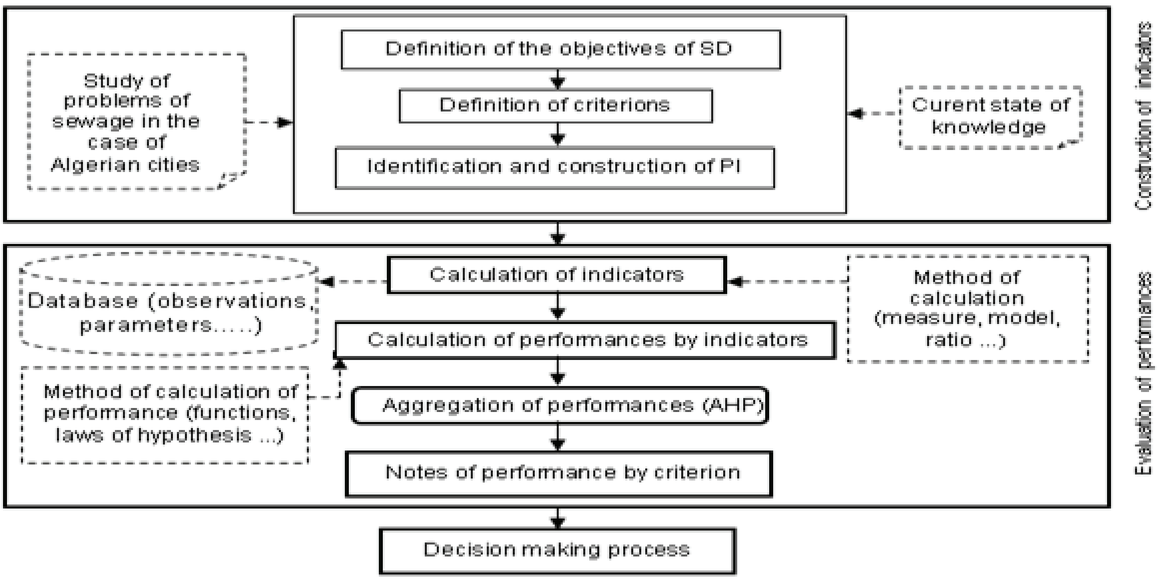


Fig.1 : General flowchart of evaluation of performances

2.2 Definition of objectives and performance indicators

2.2.1 Objectives of durability

This study made it possible to propose a first prospect for various actions necessary for a sustainable development, as well as objectives awaited through these actions. These objectives constitute the reference allowing to appreciate and to evaluate the sewer system durability:

1. To protect the environment of the sewer system,
2. To preserve the health, the hygiene and the safety of users and personnel,
3. To protect the structural quality of the sewer network,
4. To ensure the quality of exploitation of the network,
5. To ensure a good operation of the sewer system,

6. To optimize the economic management and methods of financing,
7. To have a good institutional framework about urban sewer systems.

In this study, we treat only the fifth objective which shows the operational aspect of the sewer system (network and WWTP). It was applied to the sewer system of the town of Jijel.

2.2.2 Performance indicators

We have selected performance indicators on the basis of problems often encountered and priorities announced (CATE, 2004; Cherrared M. & al, 2007). For network's operation, the wanted performance relates to the flood problem, the wastewaters discharges (without treatment), the connection to the sewer network and the consumption of energy (Guérin-Schneider L. & al, 2003; Shuping L., & al, 2006). For the WWTP, one is interested per hydraulic and treatment capacities, the treatment output and the energy consumption of the WWTP (Table 1). At the end of this document, we present the description of parameters used to calculate indicators.

2.3 Methodology of performances evaluation

The methodology suggested is characterized by two levels of performance evaluation. The first level relates to the attribution of a note of performance for each indicator, starting from the value of the calculated indicator. The second level relates to the calculation of the performances of each criterion starting from the aggregation of performance indicators obtained in the first level.

2.3.1 Level1: Performance per indicator

The performance indicators are evaluated by one of the following processes:

- Ground Investigations, example of the number of wastewater discharges,
- Models of calculation, example of the rate of flooded areas, obtained by using SWMM model,
- Analytical methods of calculation, example of the rate of wastewater discharges.
- Measurements data, example of the leakage rate in the network, obtained by confronting measurements of entry and exit flows (input-output).

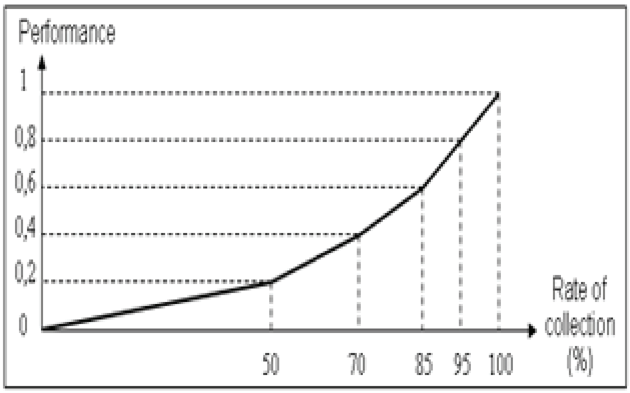


Fig.2 : Example of selected performance function for the indicator "Rate of collecting" (RNDE, 1998)

The indicator performance note can be defined per two ways: either starting from a performance function, it can be a discrete function, continuous, linear or logarithmic (figure 2); or starting from the assumption rules deduced from bibliographical analyses, ground experiments or opinions of experts to give a performance note for each indicator.

2.3.2 Level 2: Performance per criterion

It is at this level that one can extract clearer knowledge concerning the sewer system and makes decisions. The performance of a criterion is calculated starting from the performances of indicators which are associated with it (Ellis J. B. et al, 2004). This calculation is carried out according to two stages: determination of the weights of indicators and then the aggregation of performances of indicators to obtain finally a performance note for each criterion.

2.3.2.1. Determination of the weighting coefficients

We have used two methods: the first is the AHP method (Analytical Hierarchy Process), the second is what we have proposed in this study (§ b).

a. AHP Method

The AHP method is divided into four stages (Saaty T. L., 1996): classification of indicators per importance from the most important to least important, construction of a matrix starting from the comparison of indicators two at a time, determination of the weights of each indicator by an approximate method of calculation of the clean vectors and finally checking of consistency of the result.

Objective	Components of the system	Criteria	Performance indicators			
			Designation	Unit	Calculation method	Impact
To ensure the good operation of the sewer system	Le sewer network	C_1 : Collection state	Rate of wastewater discharges	m^3/year/inhab	$I_{1.1} = (V_d / N_{inhab}) \times 100$	To protect the natural environment, and to preserve the health and the hygiene of the users
			Rate of the collection to the WWTP	%	$I_{1.2} = (V_{WWTP} / V_{col}) \times 100$	
			Rate of the leakage in the sewer network	%	$I_{1.3} = (N_{Leakage} / L_{network}) \times 100$	
		C_2 : Flood risk	Rate of the flooded areas	%	$I_{2.1} = (A_{Flooded} / A_{overall}) \times 100$	To protect people and structures
		C_3 : Consumption of electrical energy (pumping station)	Consumption of energy per inhabitant	KWh/inhab/year	$I_{3.1} = E / N_{inhab}$	To reduce the costs of the sewer network exploitation
			Consumption of energy per cubic meter of water	KWh/m^3	$I_{3.2} = E / V_{PS}$	
			Cost of energy per inhabitant	KDA*/inhab/year	$I_{3.3} = C / N_{inhab}$	
			Cost of energy per linear meter of the network	KDA*/ml/year	$I_{3.4} = C / L_{PS}$	
	The WWTP	C_4 : Allowed pollutant load at the entry	Rate of allowed TKN	%	$I_{4.1} = (M_{TKN} / M_{TKN(max)}) \times 100$	To maintain the good operation of the WWTP
		C_5 : Allowed hydraulic flow at the entry	Rate of allowed hydraulic load	%	$I_{5.1} = (V_{WWTP} / V_{WWTP(n)}) \times 100$	To ensure a good assumption of responsibility of the WWTP
		C_6 : treatment output	Output treatment in : BOD_5, COD, SS, TKN, Pt	%	$I_{6.1} = ((C_{entry} - C_{exit}) / C_{entry}) \times 100$	To protect the natural environment
		C_7 : Consumption of electrical energy	Consumption of energy per inhabitant	KWh/inhab/year	$I_{7.1} = E / N_{inhab}$	To optimize the energy expenditures
			Consumption of energy per cubic meter of water	KWh/m3	$I_{7.2} = E / V_{WWTP}$	
			Cost of energy per inhabitant	KDA*/inhab/year	$I_{7.3} = C / N_{inhab}$	
			Cost of energy per linear meter of the network	KDA*/ml/year	$I_{7.4} = C / L_{PS}$	

* 1 Euro = 100 DA roughly

Symbols used to calculate indicators are defined in the end of this article

Table 1: Synthetic presentation of the performance indicators

a.1. Classification of indicators per importance.

This stage consists to establish the priorities between indicators pertaining to the same criterion according to the principle of importance. For example, I_1, I_2,…,I_i…..,I_n are the whole of indicators of which one seeks the weighting coefficient. According to the principle of hierarchisation, I_1 is more important than I_2 which is more important than I_{i-1}, which is more important than I_i. Finally, I_n is the least important indicator.

a.2. Comparison of indicators per importance.

In order to establish the preferences, a scale of values must be selected to specify the degree of importance of an indicator compared to another. We adopt the scale of value from 1 to 9 (Harker, P. T., 1989), allowing to introduce the judgements of the decision maker closer to reality. For example, if indicator I_i has an essential importance compared to the I_j indicator, the ratio w_i/w_j will be equal to 5. The comparison between all indicators gives the following matrix (equation 1):

$$A = \begin{bmatrix} a_{11} & \ldots & a_{1i} & a_{1j} & \ldots & a_{1n} \\ \ldots & \ldots & \ldots & \ldots & \ldots & \ldots \\ a_{i1} & \ldots & a_{ii} & a_{ij} & \ldots & a_{in} \\ a_{j1} & \ldots & a_{ij} & a_{jj} & \ldots & a_{jn} \\ \ldots & \ldots & \ldots & \ldots & \ldots & \ldots \\ a_{n1} & \ldots & a_{ni} & a_{nj} & \ldots & a_{nn} \end{bmatrix} \quad (1) \quad \text{With } aij = \frac{w_i}{w_j} \text{ and } a_{ii} = 1$$

a_{ij} is the intensity of the importance of I_i on I_j and w_i the weighting coefficient associated with I_i.

a.3. Determination of weighting coefficients associated with each indicator.

In this stage, we calculate the vector of the weighting coefficients W = {w_1…w_2…w_n}. For that, we divide each a_{ij} per the sum of values of the corresponding column and then we make an average per line. Thus, each coefficient w_i is obtained by the equation (2). The sum of w_i must be equal to 1.

$$w_i = \frac{\sum_{i=1}^{n}\left[a_{il} / \sum_{k=1}^{n} a_{kl}\right]}{n} \qquad (2)$$

a.4. Verification of the consistence of results.

A great advantage of the method is that it calculates a coherence index, which makes it possible to evaluate the elaborated calculations. In other words, it permits to check if the values of the scale (1-9) attributed by the decision-maker are coherent or not. It provides a measurement of the probability that the matrix was entirely supplemented at random. For example, if the CR ratio is equal to 0.20, it means that there is a chance of 20% that the decision maker answered the questions in a purely random way. We define the vectors $\left[\lambda'_1 \ldots \lambda'_i \ldots \lambda'_n\right]$ and $\left[\lambda_1 \ldots \lambda_i \ldots \lambda_n\right]$ per equations (3) and (4):

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

And: $\lambda_i = \dfrac{\lambda'_i}{w_i}$ (4), then, we obtain: $\lambda_{max} = \left[\sum_{i=1}^{n} \lambda_i\right] / n$

So, the consistence index is: $CI = (\lambda_{max} - n)/(n-1)$

To calculate the consistence ratio (CR), we divide the consistence index on a RI value depending on the indicator number N given by table 2:

Size of the matrix (n)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0,00	0,00	0,58	0,90	1,12	1,24	1,32	1,41	1,45	1,49	1,51	1,53	1,56	1,57	1,59

Table 2: Values of the coefficient (RI)

The attribution of weights is considered to be acceptable if CR is lower than 0,1. Otherwise, the procedure has to be applied yet again.

b. The Proposed weighting method

The weights of indicators are given starting from the values of calculated indicators. For example, for the criterion "Treatment output", weights of the indicators R_{BOD5} and R_{COD} are calculated respectively by the equations (5) and (6):

$$w_{BOD5} = \frac{R_{BOD5}}{R_{BOD5} + R_{COD} + R_{SS} + R_{Nt} + R_{Pt}} \quad (5), \quad w_{COD} = \frac{R_{COD}}{R_{BOD5} + R_{COD} + R_{SS} + R_{Nt} + R_{Pt}} \quad (6).$$

$R_{BOD5}, R_{COD}, R_{SS}, R_{Nt}, R_{Pt}$: are the treatment outputs of the WWTP, for considered parameters.

2.3.2.2. Aggregation of indicators

For our problem, we have opted for a complete aggregation; i.e. the inclusion of the whole of indicator performances in a mathematical formula for obtaining a single performance value for each criterion (Bouyssou D. et al, 2003). The selected aggregation method is the method of linear additions (known as the method of the weighted sum), which is also one of the most used methods (Saheli H. A. et al, 2005). This method consists in attributing a performance note to each indicator (PI_i), which will be multiplied per a weighting coefficient (w_i). The sum of N indicators gives an aggregated performance result expressed in a global note (equation 7):

$$PC_j = \sum_{i=1}^{n} PI_{ji} \times w_i \quad (7)$$

With:

PC_j : performance note for the criteria (C_j)
PI_i : performance note for the indicator (I_i) of the criterion (C_j)
w_i : weighting coefficient for the indicator (I_i) of the criteria (C_j)

3 PRINCIPLE OF THE DATA-PROCESSING MODEL

The elaborated and used tool is the data-processing transcription of the evaluation methodology of durability, described in section 2.3. The data entered by the user, about the sewer system, are stored in a database and classified per project. First, we select criteria and indicators to be evaluated (figure 3). So, a computing process is launched. It includes the following operations:

- Calculation of performance indicators,
- Calculation of performances for each indicator,
- Determination of the weighting coefficients (AHP method),
- Aggregation of indicator performances and calculation of performances for each criterion.

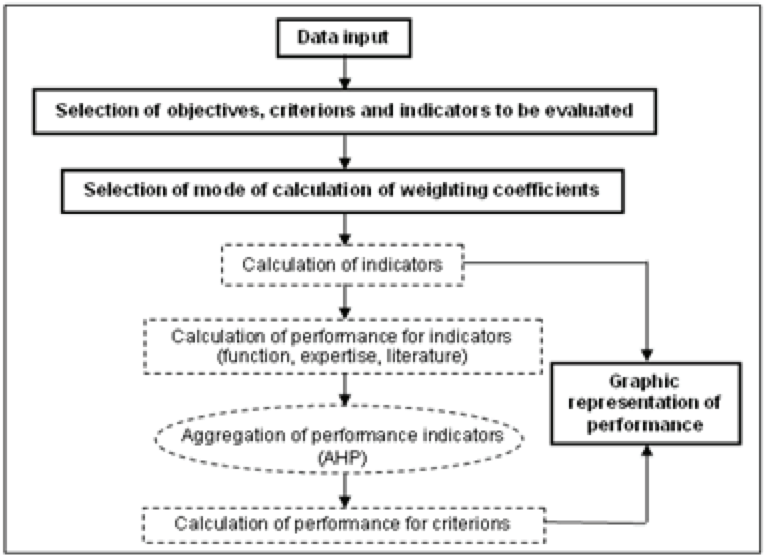


Fig. 3 : principle of the data-processing model

4 APPLICATION TO THE SEWER SYSTEM OF JIJEL'S CITY

4.1 Presentation of the site

The population of Jijel is estimated at 135.000 inhabitants (SCE, 2009). The sewer network is characterised by 92% of combined network and 8% of separative network. The length of the network is 113 km. The catchment is characterized by eight zones of which the half of discharges flows in the natural environment. We count 56 direct discharges primarily concentrated in the Mautas wadi. The water volume discharged directly in the natural environment is estimated about 3000 m^3/day (SCE, 2009). The network is mainly gravitating; it contains five pumping stations of which three are connected to the WWTP (figure 4).

The wastewater treatment mode is with activated sludges at weak load. Daily volume arriving at the WWTP is about 9.400 m3/j knowing that the maximum capacity of the WWTP is of 30 000 m3/j. The WWTP is dimensioned to treat 150.000 inhabitants.

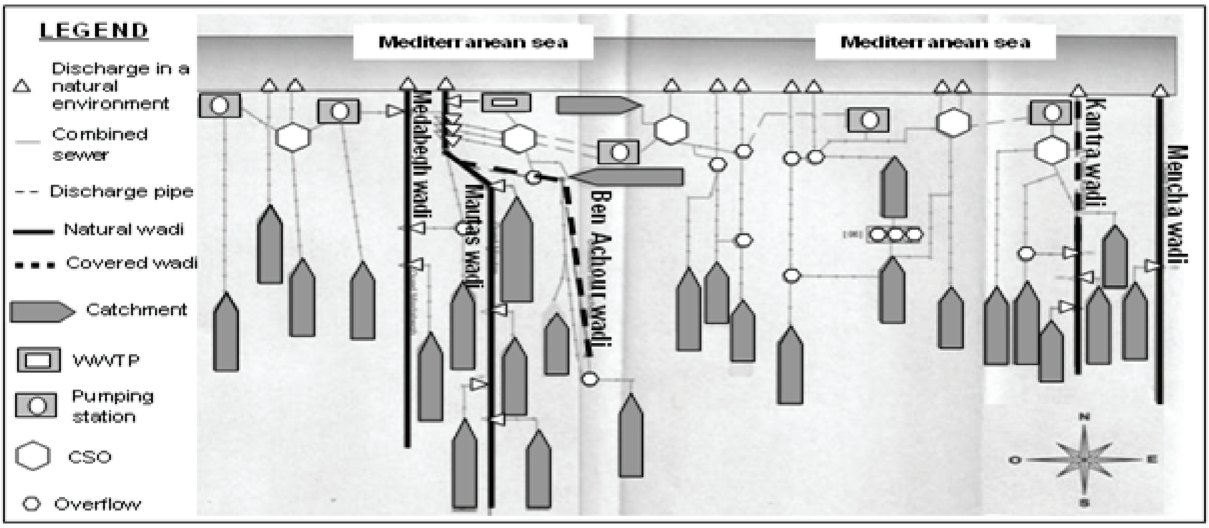


Fig.4 : Synoptic schema of Jijel's sewer system

4.2 Obtained results

The obtained results come from the application of the elaborated tool according to the flow chart of figure 3. The results of performances are presented for the two levels: indicator and criterion.

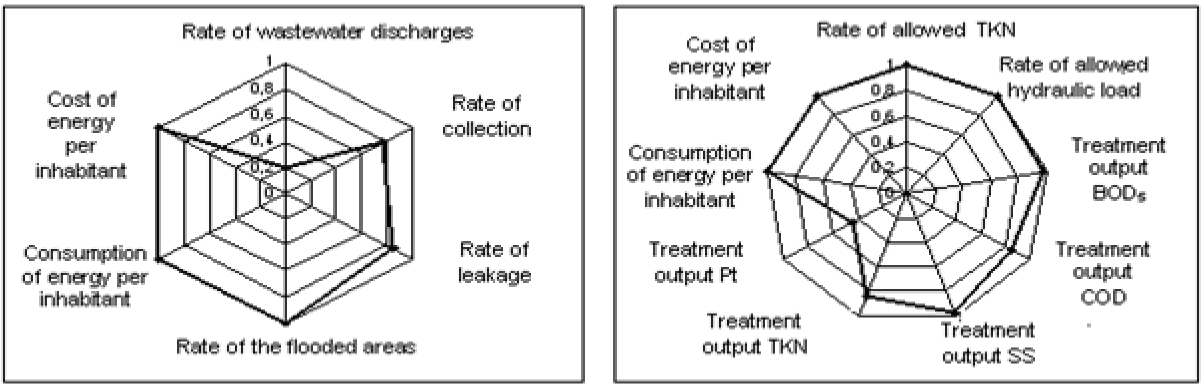
4.2.1 Performance results per indicator

4.2.1.1. Network performance

The operational indicators of the sewer network are considered as good, except for the rate of direct rejection in a natural environment which is regarded as bad (figure 5-a). This result is confirmed by the bad water quality observed upstream of the WWTP discharges that is caused by a great number of discharges along the sewer network primarily concentrated on the Mautas Wadi. The impact on this wadi is particularly important because an anoxia was observed at its mouth. It is much recommended, immediately, to design peripheral collectors on each bank of the Mautas Wadi in order to collect the discharges and to transfer them towards the WWTP. The values of annual energy consumption are reported in tons equivalent oil (TEO) according to the conversion factor (Observatoire de l'énergie, 2003).

4.2.1.2. WWTP performance

According to the results obtained (figure 5-b), the WWTP has a good treatment output with a quality of the rejections which respects the standards imposed by the Algerian regulation (RADP, 1993). For the indicator "total phosphorus output (Pt)", the performance is bad because the total phosphorus concentration at the entry of the WWTP is too much weak and it is even close to the standard. The pollutant load and the hydraulic load measured at the entry of the WWTP are very weak compared to the dimensioning loads for all parameters. Nevertheless, one must know that a bad direction of the WWTP can cause dysfunctions of the treatment equipments in the long run.



a) – Indicators related to the sewage b) – indicators related to the WWTP

Fig. 5 : Performances per indicator

4.2.1.3. Comparison between measured and calculated indicators

The values of the measured indicators and those calculated theoretically are relatively the same, except for the rate of TKN (Total Kjeldahl Nitrogen) admitted at the WWTP. The TKN pollutant load calculated starting from the ratios of production of theoretical pollution (Observatoire de l'énergie, 2003) is more important than measured at the entry of Jijel's WWTP (figure 6). This is because the real production in TKN on the whole of the Jijel's network is very different from that measured due to the great difference between the produced quantities and the quantities which arrive really at the WWTP (losses upstream of the WWTP due to the wastewater discharges, etc).

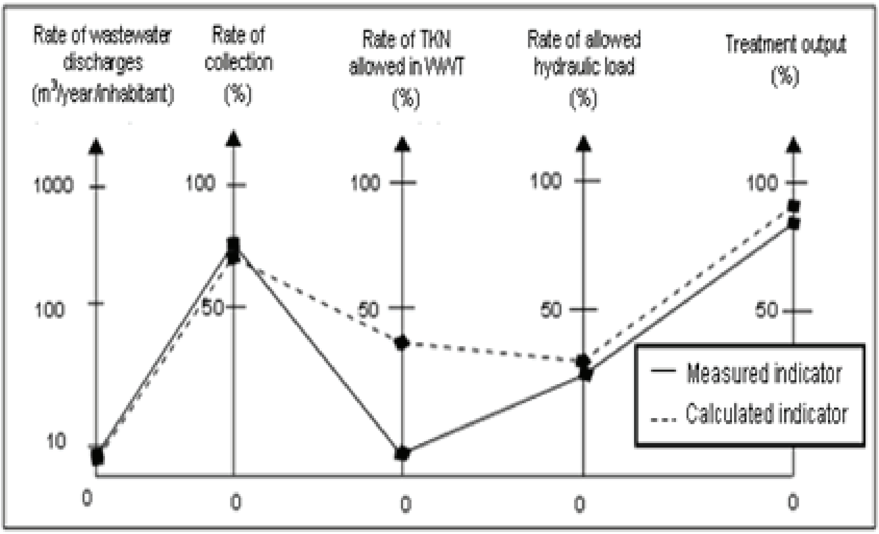


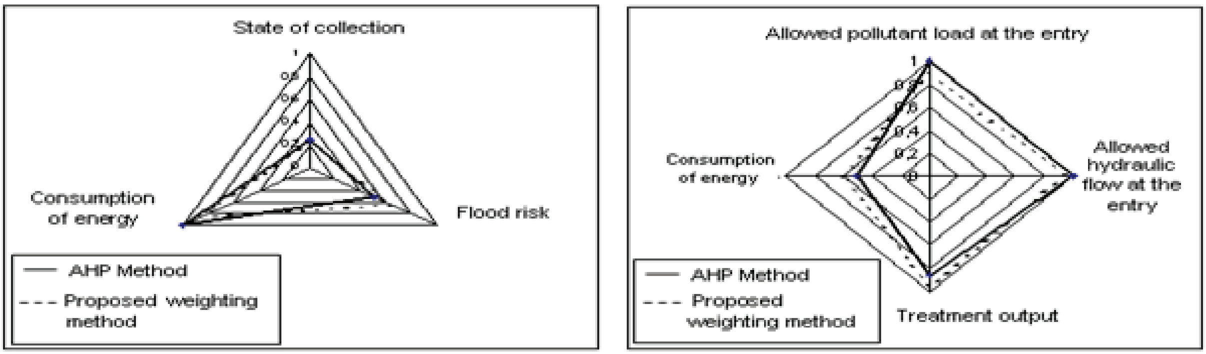
Fig. 6 : Values of performance indicators

4.2.2 Results of performances per criteria

The quality of the sewer network operation is bad (figure 7-a). Improvements remain to be envisaged for the collection state and it is necessary to refit the floodplains which are in agglomeration. The quality of the WWTP operation is regarded as acceptable (figure 7-b), considering the volume of the waste water currently treated which remains very low than its treatment capacity (SCE, 2009).

The obtained results reveal that the choice between both methods (§ 2.3.2.1 a. and b.) is based on the calculation ways of weighting coefficients. These calculation ways remain to be developed in both cases. The great limitation of this type of method is the time (and the cost) necessary to make the indicators calculation and to gather data especially.

In order that the obtained results could be easily exploitable by the manager of the sewer system and the developed tool could be of a great flexibility, we proposed to offer a prototype of instrument panel for the control of performances of the sewer system starting from the obtained results (figure 8).



a) – Criterions related to the sewage b) – Criterions related to the WWTP

Fig.7 : Performances by criterion

5 CONCLUSION

After the application of the elaborated methodology on the sewer system of Jijel's city, we have observed the limits of the suggested method for the calculation of the system performance. One of the method limits is due to the fact that calculations are based on parameters which are resulting from other calculations. That involves dependence with respect to other tools whose user does not control the outputs. The other limit lies in the aggregation of the criteria. To give a note of the performance for each objective, it is necessary to aggregate the performances of the criteria; this makes the loss of information significant at the time of the passage of a performance level to another.

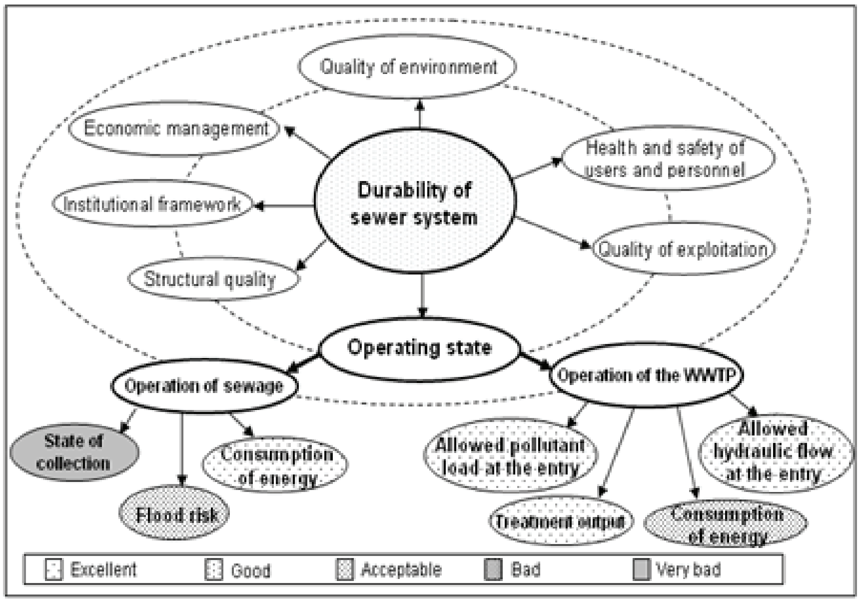


Fig.8: Dashboard of performance by criterion

The evaluation method of performances (AHP) remains clear and simple for use. New aspects could be taken into account in the form either of indicators (e.g. rate of black points in the network), or of criteria (risk of urban harmful effects). Concerning the aggregation of indicators and criteria, the mode of determination of weighting coefficients is less transparent but remains comprehensible and practical and it allows especially the checking of the coherence of choices.

The validation of methodology can be carried out by a research of references. This requires that the suggested method be applied to several cases of study in order to obtain sufficient statistics.

Only dialogue and negotiation can indeed allow choosing realistic and applicable indicators. And this enables to elaborate a method based on the use of these indicators and to lead to a reasoned and satisfactory decision. We hope that with such powerful tools at disposal, we can convince the decision makers about the interest to implement them.

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DEFINITION OF SYMBOLS

V_d : annual wasteater volume discharged directly into the natural environment (m^3/year)
N_{inhab} : total number of inhabitants connected to the network (inhab)
V_{WWTP} : annual volume of wastewater at the entry of the WWTP (m^3/year)
V_{col} : annual theoretical volume of the collected wastewater (m^3/year)
$N_{Leakage}$: leakage number per annum (U/year)
$L_{network}$: Overall length of the network (km).
$A_{Flooded}$: flooded area (m^2)
$A_{overall}$: overall surface of the catchment (m^2)
E : consumed annual total energy (KWh/year)
V_{PS} : pumped annual volume (m^3/an)
C : Total annual cost of energy (KDA/year)
N_{inhab} : number of inhabitants
L_{PS} : Overall length of the network upstream of the pumping station (km)
M_{TKN} : average pollutant load of TKN at the entry of the WWTP (kg/day)
$M_{TKN(max)}$: maximum pollutant load of TKN (Kg/day)
$V_{WWTP(n)}$: Nominal volume (Kg/day)
$C_{entry,\ Cexit}$: measured concentration successively at the entry and exit of the WWTP (mg/l)

DEFINITION OF THE ABBREVIATIONS

CNES : Conseil National Economique et Sociale
CATE : Commission de l'Aménagement du territoire et de l'environnement
RADP : République Algérienne Démocratique et Populaire
SCE : Société de Conseil en Environnement
PDAU : Plan du Développement et d'Aménagement Urbain