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A DECISION SUPPORT TOOL FOR ASSESSING WASTEWATER TREATMENT PLANT MANAGEMENT: THE CASE STUDY OF BEJAIA, ALGERIA

This study proposes a decision-support tool to improve the performance of wastewater treatment plants (WWTPs) operating in Bejaia, Algeria. The aim is to detect anomalies in WWTP management through evaluation. The model combines a top-down definition of objectives, criteria, and key indicators with a bottom-up evaluation based on reference values. Structured around 32 indicators linked to four criteria, it provides an optimization tool for WWTP operation. The model was tested on the Sidi-Ali Lebhar WWTP in Bejaia, demonstrating acceptable performance and highlighting its potential for wider application in contexts with limited financial resources.

1. INTRODUCTION

Recently, the cities of Algeria have been facing demographic growth, uncontrolled urbanisation, and high concentrations of pollutants in rivers [1]. This context has led public authorities to construct wastewater treatment plants (WWTPs). Thereby, they created the National Sanitation Office (ONA), which was charged with supervising these facilities. Currently, Algeria has 220 WWTPs, most of which are managed by the ONA, local

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People's Assemblies, or public water services [2]. The government has heavily invested in these facilities; however, many WWTPs suffer from design, operation, and management problems due to limited resources, lack of qualified personnel, and inadequate regulations [3, 4]. All these constraints create complex challenges for WWTP managers, such as recurrent failures, poor management of by-products, and pollution of the marine environment. The main goal of WWTP management consolidation is to identify and resolve identified issues.

To improve the management of WWTPs, the ONA needs a framework that quantitatively assesses performance gaps in various treatment processes. Consequently, the integration of performance indicators (PIs) appears to be an important element in this approach [5]. These latter are fundamental to optimise the management of WWTPs and provide an accurate and impartial assessment of performance, by identifying the areas requiring improvement. PIs also enable continuous monitoring by supporting decision making and alerting quickly to potential problems. This decision-making mechanism assists in choosing the optimal solution, spotting potential failures, and planning their resolution [6]. Further, the PIs promote the comparison between different treatment units by supporting the adoption of best practices. This approach strengthens the transparency and accountability in operations, enhancing stakeholder trust. By optimising the use of financial, human, and material resources, the PIs generate more cost-effective and sustainable operations. With respect to environmental and regulatory objectives, the PIs assess the compliance with discharge standards to protect the ecosystem.

In the 1990s, numerous studies were carried out to assess the performance of WWTPs and the quality of their services using specific indicators [7–10]. Advanced research has also been conducted to analyse the efficiency and energy effectiveness of wastewater treatment systems [11–13]. These studies allowed for a better understanding of the WWTPs' performance and the identification of the best practices. The purpose is to ensure a high-quality service and to preserve the environment.

The research conducted by Benzerra et al. [3] was the first to introduce the PIs concept into the urban drainage system (UDS) in Algeria. These researchers have developed a hierarchical approach composed of objectives, criteria, and PIs to measure the sustainability of UDS. They used the decision support methods such as the Analytic Hierarchy Process (AHP) and multi-criteria ranking techniques. Igroufa et al. [14] have developed an assessment framework to support the management of infrastructure assets related to UDS. Their work enabled the implementation of a structured methodology to assess the reliability, availability, and maintainability of infrastructure assets, which contributes to a more effective management of UDS. Furthermore, Bedjou et al. [4] focused on the assessment and prioritisation of defects in UDS. All this work highlighted the weaknesses of UDS in Algeria.

Regardless of the wealth of literature in this field, there is still no assessment of WWTPs management in Algeria. Consequently, our study represents the first national attempt to set up a decision-support framework based on PIs. This research describes the decision-making method to optimise the management of WWTP. The methodological approach adopted is based on two main phases: the first focuses on identifying the objectives, criteria, and pertinent indicators, taking into account the financial and human resources available at the ONA of Bejaia. The second focuses on the assessment of the system's performance, normalizing the indicators based on reference values. The framework and the approach were applied to a WWTPt in Sidi Ali Lebhar, Bejaia, northeast of Algeria.

2. METHODOLOGICAL APPROACH

2.1. GENERAL

The management assessment of WWTP is a complex process. It requires the analysis of various aspects such as environmental performance, regulatory compliance, sludge management, and energy consumption [11–13]. To conduct this analysis successfully, the methodology adopted combines two main approaches: the top-down approach and the bottom-up approach.

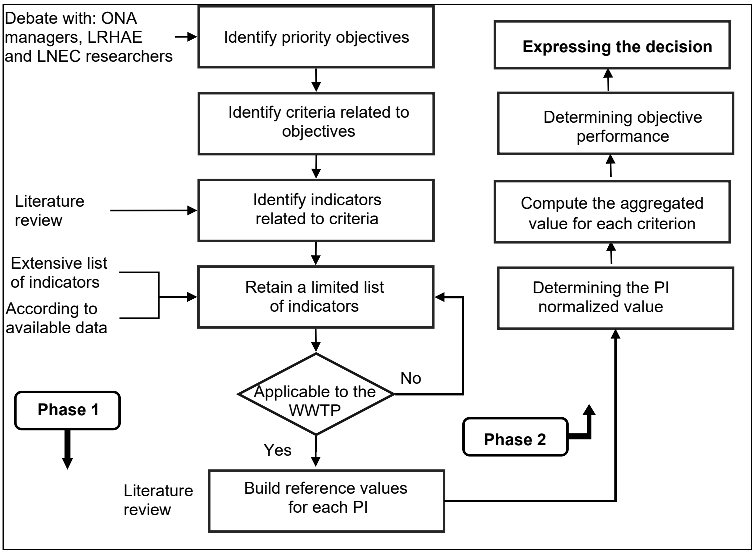

Fig. 1. Scheme of the methodology adopted

The top-down approach begins the assessment by adopting a global view of the WWTP. It involves establishing the key elements upon which the process will be based, thereby identifying the most critical aspects and priority objectives [15]. This approach provides a hierarchical perspective by simplifying the complexity of the system. It also helps prioritise general aspects before delving into the details.

The bottom-up approach generates an overall performance assessment of the elaborated model, based on various criteria and PIs' normalised assessment [6, 16]. Figure 1 illustrates the method adopted. This methodology enhances the assessment's robustness due to its participatory and hybrid nature. It addresses every issue related to the management of WWTPs.

2.2. SYSTEM BOUNDARIES

The concept of "system boundaries" is often discussed in systems management theory. It refers to the limits that define what is included or excluded from a specific system. Understanding these boundaries is essential for identifying the key components of the system. Additionally, it is important to analyse the system's functions and its interactions with the environment [17].

In our study, the boundaries become clearer when the objective, the criteria, and the PIs are defined. These boundaries encompass various aspects of wastewater treatment, including the equipment used, the flow of materials and energy, and the environmental interactions. Additionally, they cover the stakeholders involved, pumping equipment, monitoring and control systems, as well as the facilities for managing residual sludge.

Assessing the performance of WWTP management requires appropriate technical tools, qualified personnel, and sufficient financial resources. In developing countries such as Algeria, these resources could be limited, which can hinder both sector development and environmental protection. The outdated equipment and absence of self-financing mechanisms are particularly concerning. Therefore, it is essential to consider the local context and the available resources when defining the criteria and PIs for assessing WWTPs performance.

2.3. PERFORMANCE ASSESSMENT SYSTEM DEVELOPMENT

The construction of the performance assessment system is based on a hierarchical structure organised into objectives, criteria, and indicators [18]. Each objective is defined by a set of criteria, and each criterion is associated with several indicators (top-down approach). However, the use of standard indicators often faces challenges due to the financial and material constraints, as well as the availability and relevance of data related to the system being evaluated. To address these issues, it is essential to refine each proposed indicator to ensure its feasibility and suitability for local specificities.

The process of contextualising the indicators involved two main steps. Firstly, the standard indicators identified in the literature [7–12, 19] were analysed and compared with the needs expressed by stakeholders. Then, new local indicators were developed to fill the gaps in the initial list. As a result, the final set consists of 75% standard indicators and 25% local indicators, enabling a comprehensive assessment tailored to the local context.

This approach is based on a careful analysis of the local conditions. It covers the operation of facilities, the availability of data, and the key elements in assessing WWTP management. This analysis was conducted through several discussion group meetings involving the members of the Research Laboratory of Applied Hydraulics and Environment (LRHAE), ONA managers, and researchers from Portugal's National Civil Engineering Laboratory (LNEC). The number of participants in these discussions typically ranged from 7 to 9. It allows a diversity of perspectives and a collaborative approach to developing indicators.

2.4. OBJECTIVE AND CRITERION PERFORMANCE SCALE

The assessment methodology utilises a "bottom-up" approach, evaluating the performance of a complex system from its basic elements to a comprehensive global view [15]. The PIs require reference values to judge the performance, and three levels were used: "good", "acceptable", and "unsatisfactory" performance. These scales are developed from a literature review that incorporates Algerian and international standards, as well as scales proposed during discussions with the working group. The indicators for each criterion are calculated and compared to the reference values, and then they should be normalised in order to be aggregated to determine the final value of the criterion and the objective. A scale ranging from 0 to 100 is used, where 100 represents the best performance, and 0 is the worst, with "unsatisfactory" performance for values less than or equal to 70; acceptable performance between 70 and 90; and good performance above 90. These normalised values are then aggregated to assess the criteria and the objective, taking their respective weights into account.

3. PERFORMANCE ASSESSMENT SYSTEM

A performance assessment system (PAS) is an important tool for effectively managing WWTPs and optimising their efficiency [8]. This PAS adheres to the ISO 24510 and ISO 24511 standards, as well as the International Water Association (IWA) PI systems, which outline the objectives, the criteria, and the indicators [8]. The PIs developed in this study are based on the Portuguese PIs used to assess the overall performance of WWTPs [8, 10]. We have categorised them into four assessment criteria (Fig. 2): environmental protection (10 PIs), improvement of the quality of service provided to users (4 PIs), improvement of human resource management (8 PIs), and assessment of natural resource utilisation, production and recovery of treatment by-products (10 PIs).

PIs are ratios that measure the relationship between different variables, regardless of whether they are of the same type. They can be expressed in various forms, including percentages, dimensionless values, or intensities (e.g., kWh/m^3). These indicators are calculated for a reference period of one year and can be used to track performance changes over time [18].

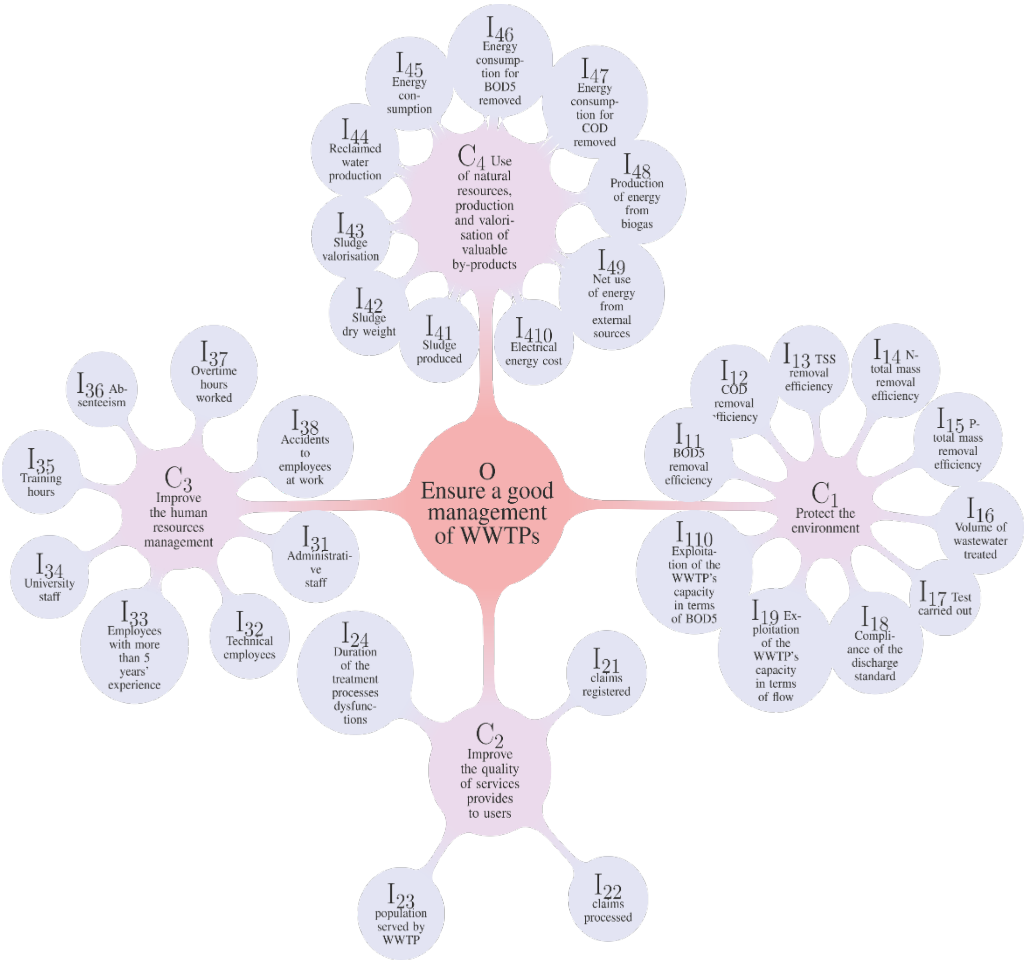

Fig. 2. Performance assessment framework

Each PI is assigned a unique code for classification and differentiation. For example, I_{11} denotes the first indicator of the first assessment criterion. The performance of the indicators is displayed in Tables 1–4. PIs with good performance were marked (++), acceptable (+), and unsatisfactory (−). The criterion of environmental protection is highly significant within the social community, as it constitutes the most prominent factor in the classification of risk [20]. This criterion evaluates WWTP's performance in terms of compliance with discharge requirements (Table 1). It focuses on key aspects, including the discharge of wastewater into the receiving environment and the quality of the treated wastewater. The assessment includes the efficiency of pollutant removal with specific indicators (I_{11}, I_{12}, I_{13}, I_{14}, I_{15}), as well as the effectiveness of the discharge permit regulations in terms of the number of analyses (I_{17}) and of compliance with the parametric values of various pollutant parameters (BOD_5, COD, TSS, P, N, I_{18}). Additionally, the volume of treated wastewater is compared to the volume inflow to the WWTP (I_{16}), allowing the assessment of the facility's performance in terms of efficiency and reliability of the treatment process, as well as the exploitation of the WWTP (I_{19}, I_{110}). I_{18} requires a comprehensive analysis of the parameters, incorporating all samples carried out during the assessment period and the comparison with the discharge standards.

Table 1

PIs for Criterion 1. Protect the environment

Key PIs [%]	Variables	Calculation method	Reference values
I_{11}: BOD5 removal efficiency BOD5	I_{11a}: mass of BOD_5 influent, kg/year I_{11b}: mass of BOD_5 effluent, kg/year	$I_{11} = \frac{I_{11a} - I_{11b}}{I_{11a}} \times 100$	[90; 100] (++) [70; 90[(+) [0; 70[(–) [11]
I_{12}: COD removal efficiency	I_{12a}: mass of COD influent, kg/year I_{12b}: mass of COD effluent, kg/year	$I_{12} = \frac{I_{12a} - I_{12b}}{I_{12a}} \times 100$	≥ 85 (++) [75; 85[(+) [0; 75[(–) [3]
I_{13}: TSS removal efficiency	I_{13a}: mass of TSS influent, kg/year I_{13b}: mass of TSS effluent, kg/year	$I_{13} = \frac{I_{13a} - I_{13b}}{I_{13a}} \times 100$	[93; 100] (++) [70; 93[(+) [0; 70[(–) [11]
I_{14}: N-total mass removal efficiency	I_{14a}: mass of N-total influent, kg/year I_{14b}: mass of N-total effluent, kg/year	$I_{14} = \frac{I_{14a} - I_{14b}}{I_{14a}} \times 100$	[85; 100] (++) [70; 85[(+) [0; 70[(–) [11]
I_{15}: P-total mass removal efficiency	I_{15a}: mass of P-total influent, kg/year I_{15b}: mass of P-total effluent, kg/year	$I_{15} = \frac{I_{15a} - I_{15b}}{I_{15a}} \times 100$	[80; 100] (++) [70; 80[(+) [0; 70[(–) [11]
I_{16}: volume of wastewater treated	I_{16a}: treated wastewater, m^3/year I_{16b}: raw wastewater, m^3/year	$I_{16} = \frac{I_{16a}}{I_{16b}} \times 100$	[97; 100] (++) [90; 97[(+) [0; 90[(–) [21]
I_{17}: test carried out	$I_{17a} = \sum_i^n T_i$ i – patameter, n – total of parameters, T_i – tests carried out on treated wastewater, No./year I_{17b} – tests required, No./year	$I_{17} = \frac{I_{17a}}{I_{17b}} \times 100$	≥ 100 (++) [90; 100[(+) < 90 (–) [12]

Table 1

PIs for Criterion 1. Protect the environment

I_{18}: compliance of the discharge standard	$I_{18a} = \sum_{i}^{n} K_i$ K_i: compliance with the parameter i (0 – no compliance, 1– compliance) I_{18b}: parameters required, No.	$I_{18} = \frac{I_{18a}}{I_{18b}} \times 100$	100 (++) < 100 (–) [12, 22]
I_{19}: exploitation of the WWTP's capacity in terms of flow	I_{19a}: daily average of wastewater flow in the month with the highest inflow, m^3/d I_{19b}: daily capacity of the WWTP, m^3/d	$I_{19} = \frac{I_{19a}}{I_{19b}} \times 100$	[70; 95] (++) [60; 70] or]95; 120] (+) [0; 60[or]120; +∞[(–) [21]
I_{110}: exploitation of the WWTP's capacity in terms of BOD_5	I_{110a}: daily average of mass in the month with the highest BOD_5 mass influent, kg/d I_{110b}: BOD_5 mass capacity of the WWTP, kg/d	$I_{110} = \frac{I_{110a}}{I_{110b}} \times 100$	[70; 95] (++) [60; 70] or]95; 120] (+) [0; 60[or]120; +∞[(–) [21]

The indicators in Table 2 assess whether the WWTP's services meet users' expectations. Service adequacy is measured by accessibility, which looks at the availability of services for users. This is determined by the ratio of the population connected to the WWTP compared to the total population at the assessment period (I_{23}). Additionally, service quality is assessed by analysing registered complaints (I_{21}, I_{22}) and the maintenance of equipment to prevent malfunctions and ensure continuous service (I_{24}).

The human resources criterion (Table 3) assesses the performance of WWTP based on various factors: staff availability, qualifications, training, absenteeism, and overtime hours (I_{31}, I_{32}, I_{33}, I_{34}, I_{35}, I_{36}, I_{37}). The aim is to ensure optimal management of positions and operational efficiency. However, it is essential to keep a balance between performance and employee safety to ensure the effective functioning of the WWTP. Employee safety is assessed by tracking workplace accidents, including all injuries or illnesses requiring care beyond initial emergency treatment (I_{38}). The scales for these PIs were constructed in collaboration with researchers from LRHAE, LNEC, and ONA managers. The indicators of staff availability and qualifications (I_{31}, I_{32}, and I_{34}) share a common scale. A rate of 70% or less reflects a lack of staff, which may lead to certain tasks not being carried out, while a rate of over 130% indicates an overlap of tasks. On the other hand, a rate of between 90% and 110% represents an optimal allocation of posts, effectively meeting the staffing needs of the WWTP. Additionally, the scale for indicator I_{35} was derived by multiplying the staff availability rate by the number of hours required to complete their training. Although a specific scale was constructed for employees with more than 5 years of experience (I_{33}), ensuring a balance between young and old employees based on their availability in the WWTP. Finally, the scales for indicators I_{36}, I_{37}, and I_{38} were rigorously defined during participatory meetings, focusing on accident rates, absenteeism, and overtime, in order to optimise plant performance.

Table 2

PIs for Criterion 2. Improve the quality of service provided to users

Key PIs	Variables	Calculation method	Reference values
I_{21}: claims registered, No./(1000 population·year)	I_{21a}: complaints due to flooding and unpleasant odours registered per year I_{21b} population at the assessment period	$I_{21} = \frac{I_{21a}}{I_{21b}} \times 1000$	0 (++)]0; 1.1] (+) > 1.1 (–) [22]
I_{22}: claims processed, %	I_{22a}: claims processed per year	$I_{22} = \frac{I_{22a}}{I_{21a}} \times 100$	100 (++) [95 ; 100[(+) [0 ; 95[(–) [21]
I_{23}: population served by WWTP, %	I_{23a}: inhabitants served by the WWTP at the assessment period	$I_{23} = \frac{I_{23a}}{I_{21b}} \times 100$	100 (++) [85; 100[(+) [0; 85[(–) [21]
I_{24}: duration of the treatment processes dysfunction, %	I_{24a}: $\sum_{i}^{n}$ rate of dysfunction processes, % I_{24b}: $\sum_{i}^{365}$ days od dysfunction WWTP I_{24c}: days of treatment at the WWTP	$I_{24} = \frac{I_{24a} I_{24b}}{I_{24c}} \times 100$	0 Good (++)]0; 5] (+)]5; 100] (–)

The by-product management criterion assesses the WWTP's performance in terms of the production and valorisation of by-products such as sludge, biogas, and treated wastewater (I_{41}, I_{43}, I_{44}, I_{48}). They also assess the quality of sludge to determine whether it can be recovered or needs to be disposed of (I_{42}). Indicators related to the use of natural resources measure the efficiency of inputs, including energy and biogas (I_{45}, I_{46}, I_{47}, I_{49}). Overall, these indicators allow for a comprehensive assessment of the purification process by providing a complete balance of the associated consumption and production.

Table 3

PIs for Criterion 3. Improve human resources management

Key PIs	Variables	Calculation method	Reference values
I_{31}: administrative staff, %	I_{31a}: employees executing administrative tasks at the assessment period I_{31b}: employees necessary for the administrative tasks at the assessment period	$I_{31} = \frac{I_{31a}}{I_{31b}} \times 100$	[90; 110] (++) [70; 90[or]110; 130] (+) [0; 70[or > 130 (–)
I_{32}: technical employees, %	I_{32a}: employees instructed to execute technical tasks during the assessment period I_{32b}: employees necessary for the technical tasks at the assessment period	$I_{32} = \frac{I_{32a}}{I_{32b}} \times 100$	[90; 110] (++) [70; 90[or]110; 130] (+) [0; 70[or > 130 (–)
I_{33}: employees with more than 5 years of experience, %	I_{33a}: employees with more than 5 years of experience at the assessment period I_{33b}: employees in full-time equivalent at the assessment period	$I_{33} = \frac{I_{33a}}{I_{33b}} \times 100$	[60; 80] (++) [40; 60[or]80; 90] (+) [0; 40[or]90; 100] (–)
I_{34}: university staff, %	I_{34a}: employees with university degrees at the assessment period I_{34b}: employees needed for the WWTP with a university degree at the assessment period	$I_{34} = \frac{I_{34a}}{I_{34b}} \times 100$	[90; 110] (++) [70; 90[or]110; 13 0] (+) [0; 70[or > 130 (–)
I_{35}: training hours, h/employees	I_{35a}: training hours of employees per year	$I_{35} = \frac{I_{35a}}{I_{33b}}$	[57; 69] (++) [44; 57[or]69; 82] (+) [0; 44[or > 82 (–)
I_{36}: absenteeism, %	I_{36a}: employee absenteeism, hour/year I_{36b}: full-time equivalent working hours, hour/year	$I_{36} = \frac{I_{36a}}{I_{36b}} \times 100$	[0; 1] (++)]1; 5] (+)]5; 100] (–)

Table 3

PIs for Criterion 3. Improve human resources management

I_{37}: overtime hours worked, %	I_{37a}: overtime worked by employees, hour/year	$I_{37} = \frac{I_{37a}}{I_{36b}} \times 100$	[0; 10] (++)]10; 50] (+)]50; 100] (–)
I_{38}: accidents to employees at work, No./(employee·year)	I_{38a}: accidents at work requiring medical treatment, No./year	$I_{38} = \frac{I_{38a}}{I_{33b}}$	0 (++) 1 (–)

Table 4

PIs for Criterion 4. Use of natural resources, production and valorisation of valuable by-products

Key PIs	Variables	Calculation method	Reference values
I_{41}: sludge produced, kg/m^3	I_{41a}: quantity of sludge produced, kg/year	$I_{41} = \frac{I_{41a}}{I_{16a}}$	≤ 1 (++)]1; 1.5] (+) > 1.5 (–) [23]
I_{42}: sludge dry weight, %	I_{42a}: average dry matter concentration of the sludge produced, % (w/w)	$I_{42} = I_{42a}$	≥ 18 (++) [12; 18[(+) < 12 (–) [23]
I_{43}: sludge valorisation, %	I_{43a}: quantity of sludge valorised, kg/year	$I_{43} = \frac{I_{43a}}{I_{41a}} \times 100$	100 (++)]95; 100[(+) [0; 95] (–) [23]
I_{44}: reclaimed water production, %	I_{44a}: reclaimed water reused (for own use or by a third party), m^3/year	$I_{44} = \frac{I_{44a}}{I_{16a}} \times 100$	[10; 100] (++) [5; 10] (+) [0; 5] (–) [21]
I_{45}: energy consumption, kWh/m^3	I_{45a}: energy consumption, kWh/year	$I_{45} = \frac{I_{45a}}{I_{16a}}$	≤ 0.280 + 1192/TW (++) [0.280 + 1192/TW; 0.350 + 1490/TW] (+) > 0.350 + 1490/TW (–) [13]
I_{46}: energy consumption for BOD_5 removed, kWh/kg	I_{46a}: BOD_5 mass removed, kg/year ($I_{11a} - I_{11b}$)	$I_{46} = \frac{I_{45a}}{I_{46a}}$	≤ 2 (++)]2; 10] (+) > 10 (–) [13]

Table 4

PIs for Criterion 4. Use of natural resources, production and valorisation of valuable by-products

I_{47}: energy consumption for COD removed, kWh/kg	I_{47a}: COD mass removed, kg/year ($I_{12a} - I_{12b}$)	$I_{47} = \frac{I_{45a}}{I_{47a}}$	
I_{48}: production of energy from biogas, kWh/m^3	I_{48a}: electrical energy produced from biogas, kWh/year	$I_{48} = \frac{I_{48a}}{I_{45a}}$	$\geq$ 0.0009 BOD_5 (++) [0.0007BOD_5; 0.0009 BOD_5] (+) < 0.0007 BOD_5 (–) [13]
I_{49}: net use of energy from external sources, kWh/m^3	I_{49a}: energy acquired to external sources; sold to external users (kWh/year)	$I_{49} = \frac{I_{49a}}{I_{45a}}$	$\leq$ 0.280 + 1192/TW – 0.0009 BOD_5 (++) [0.280 + 1192/TW – 0.0009BOD_5; 0.350 + 1490/TW – 0.0007BOD_5] (+) $\geq$ 0.350 + 1490/TW – 0.0007 BOD_5 TW: treated wastewater, m^3/d [13]
I_{410}: electrical energy costs EUR/m^3	I_{410a}: electrical energy cost, EUR	$I_{410} = \frac{I_{410a}}{I_{16a}}$	varies by country

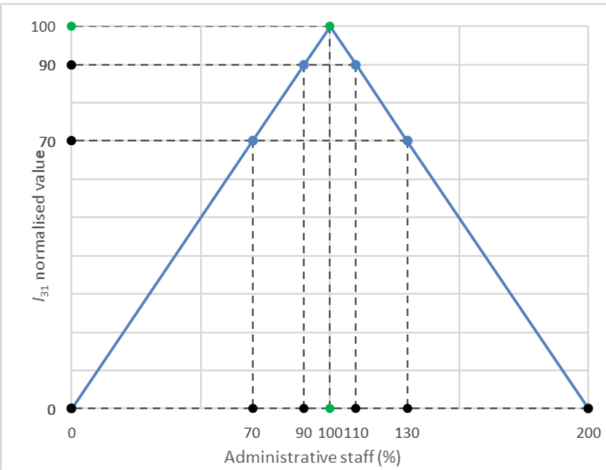

Fig. 3. The normalisation of I_{31}

The PIs should be normalised prior to the criterion aggregation (Sect. 2.4). This normalisation is achieved by using the reference values of each PI. Figure 3 shows an example of the normalisation of I_{31}.

4. APPLICATION OF THE PAS ON THE SIDI ALI LEBHAR WWTP

The assessment framework and the approach presented in the previous sections were applied to the WWTP of Sidi Ali Lebhar, located in Bejaia, north eastern Algeria. The city of Bejaia covers an area of 120.22 km^2 and approximately 185,000 inhabitants. Its Mediterranean climate is characterised by rainy and mild winters, and hot and dry summers, with an average annual rainfall of around 874 mm [14].

According to the managers of Bejaia's ONA, the sanitation system consists of two WWTPs (Bejaia and Sidi Ali Lebhar), 12 wastewater collection basins and a 425 km network, covering 98% of the population. However, only 35% of discharges are currently connected to these two WWTPs. Many discharges still flow into the wadis that traverse the city, highlighting the need for these discharges to be connected to the WWTP. Protecting the Mediterranean Sea, which receives these rivers and the discharges from the two WWTPs, is essential.

The Sidi Ali Lebhar WWTP, designed to treat both domestic and industrial wastewater, is based on an extendable activated sludge biological process. This process includes the pre-treatment and secondary treatment, as well as sludge treatment and management. By 2030, its capacity could reach 9500 m^3/d, serving around 80 000 population equivalents.

5. RESULTS AND DISCUSSION

The data needed for the indicators were collected during multiple visits to the WWTP. The data used are from 2019, as they were available prior to the Covid-19 pandemic. These calculations are then normalised (as exemplified in Fig. 3) and aggregated to determine the value of each criterion. The performance of the criteria and the objective is assessed using the performance scale presented in Section 2.4, which are aggregated to evaluate the overall performance of the objective. Figure 4 shows the results from the assessment of the studied PIs and reveals that a significant number of the indicators demonstrate poor performance. The calculated values for the selected PIs, as well as their normalization for each criterion, are presented in Table 5.

The environmental protection criterion assesses the quality of the treated water and the WWTP's compliance with discharge standards. Five indicators measure the efficiency of pollutant removal (TSS, BOD_5, COD, P, N). The results show good performance for BOD_5, COD, and TSS, with removal rates exceeding 90% (Table 5).

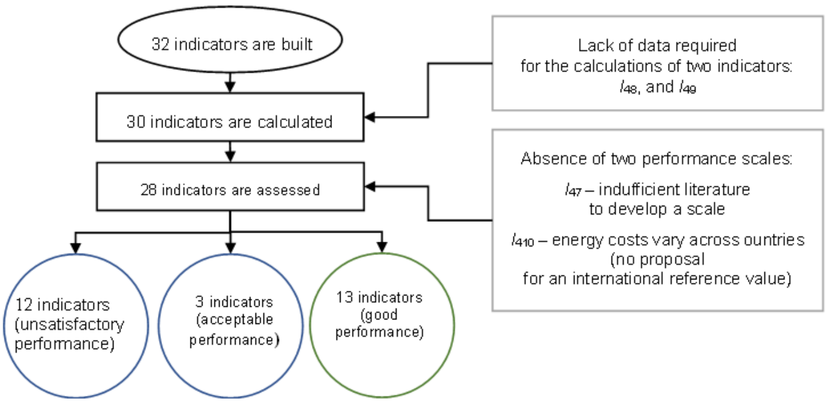

Fig. 4. The assessment results of the indicators studied

Table 5

Calculated values for the selected PIs

Key PIs	Results	Key PIs	Results
PIs of criterion 1. Protect the environment			
I_{11}: BOD$_5$ removal efficiency	I_{11} = 97.3% = 97.3 (++)	I_{16}: volume of wastewater treated	I_{16} = 98.5% = 95 (++)
I_{12}: COD removal efficiency	I_{12} = 94.6% = 96.4 (++)	I_{17}: test carried out	I_{17} = 83.3% = 64.8 (–)
I_{13}: TSS removal efficiency	I_{13} = 97.3% = 96.1 (++)	I_{18}: compliance of the discharge standard	I_{18} = 84% = 58.8 (–)
I_{14}: N-total removal efficiency	I_{14} = 69.8% = 69.8 (–)	I_{19}: exploitation of the WWTP's capacity in terms of flow	I_{19} = 74.3% = 95.5 (++)
I_{15}: P-total removal efficiency	I_{15} = 12.3% = 12.3 (–)	I_{110}: exploitation of the WWTP's capacity in terms of BOD$_5$	I_{110} = 50.7% = 59.2 (–)
PIs of criterion 2. Improve the quality of service provided to users			
I_{21}: claims registered	I_{21} = 0 No./1000 population per year = 100 (++)	I_{23}: population served by WWTP	I_{23} = 60.2% = 49.6 (–)
I_{22}: claims processed	I_{22} = 100% = 100 (++)	I_{24}: duration of the treatment processes dysfunction	I_{24} = 0.82% = 86.7 (+)
PIs of criterion 3. Improve the human resources management			
I_{31}: administrative staff	I_{31} = 100% = 100 (++)	I_{35}: training hours	I_{35} = 21 h per employee = 33.4 (–)

Table 5

Calculated values for the selected PIs

I_{32}: technical employees	I_{32} = 77.8% = 77.8 (+)	I_{36}: absenteeism	I_{36} = 0.99 % = 90.1 (++)
I_{33}: employees with more than 5 years of experience	I_{33} = 93.8% = 43.4 (–)	I_{37}: overtime hours worked	I_{37} = 0% = 100 (++)
I_{34}: university staff	I_{34} = 50% = 50 (–)	I_{38}: accidents to employees at work	I_{38} = 0 per employee per year = 100 (++)
PI of criterion 4. Use of natural resources, production and valorisation of valuable by-products			
I_{41}: sludge produced	I_{41} = 1.4 kg/m^3 = 74 (+)	I_{45}: energy consumption	I_{45} = 0.618 kWh/m^3 = 93.5 (++)
I_{42}: sludge dry weight	I_{42} = 18% = 90 (++)	I_{46}: energy consumption for BOD_5 removed	I_{46} = 10.2 kWh/kg BOD_5 removed = 69.7 (–)
I_{43}: sludge valorisation	I_{43} = 0% = 0 (–)	I_{47}: energy consumption for COD removed	I_{47} = 10.1 kWh/kg COD removed
I_{44}: reclaimed water production	I_{44} = 0.55% = 7.7 (–)	I_{410}: electrical energy cost	I_{410} = 0.02 EUR/m^3

This performance is the result of the optimal organic matter degradation in the biological tank and effective management of the activated sludge process. However, difficulties were encountered in the removal of phosphorus and in the nitrification and denitrification processes of nitrogen. The ONA reported a lack of ferric chloride for 5 months, disrupting phosphorus removal. Additionally, insufficient aeration due to foam accumulation in the biological tank hindered wastewater recycling. This issue stemmed from a lack of equipment maintenance. The availability of the chemical products and the operating conditions, such as effluent concentration, significantly influence treatment efficiency [24]. The assessment of the WWTP reliability relies on analysing the quality of treated water using two indicators: the number of analyses I_{17} and the compliance of these tests I_{18} with current regulations (Table 5). Indicator I_{17} requires 60 analyses per year (12 analyses for each of the five pollutants); however, only 50 analyses were conducted during the assessment period. This shortfall is largely due to a lack of analyses for COD and phosphorus from June to October, resulting in inadequate performance. Additional tests are only considered after the required tests for each pollutant have been performed. The results are then compared with the discharge standards (I_{18}). If a test meets the standards, the parameter k is assigned a value of 1; otherwise, $K = 0$ (Table 1, I_{18}). If indicator I_{18} falls below 100%, the WWTP does not comply with discharge regulations; the current assessment shows non-compliance for nitrogen, phosphorus, and COD. The exploitation of the WWTP capacity in terms of flow and in terms of BOD_5 is assessed by the indicators (I_{19} and I_{110}) and demonstrated that the plant is underutilized in terms of organic mass. To enhance the reliability and efficiency of the WWTP, managers need to allocate additional financial resources to ensure the availability of chemicals and improve equipment maintenance.

The assessment shows that the quality of service provided to users (criterion 2, Table 5) is low regarding the population served and the duration of the equipment failures. Currently, only 60% of the population is connected to the WWTP (I_{23}), which results in numerous discharges remaining unaddressed.

In terms of equipment performance, the biological tank was out of service for three days in February 2019, leading to a bypass of the WWTP. For indicator I_{24}, a malfunction rate was assigned for each equipment item at the WWTP in collaboration with ONA managers and researchers from the LRHAE and LNEC laboratories. The dysfunction rates of various equipment in the system are as follows. The lift station has a dysfunction rate of 40%. Both the grit channels, the desalter and deoiler units, and the thickener each exhibit a dysfunction rate of 20%. On the other hand, the dewatering facility, chlorination tank, distributor, and sludge treatment station show no dysfunction (0%). However, the settling tank and the aeration tank have the highest dysfunction rate, reaching 100%. Despite this issue, no complaints were recorded (I_{21}), likely because the odour intensity was low. To improve the quality and continuity of the service, it is necessary to increase the connection rate of the WWTP and allocate more financial resources to its maintenance.

The results for criterion 3 (Table 5) show a good occupancy of administrative positions at the WWTP (I_{31}), as evidenced by the absence of overtime hours (I_{37}). However, the number of employees with university degrees and the total training hours are still insufficient (I_{34}, I_{35}). Additionally, there is an imbalance in experience levels between younger and older employees; over 90% of older employees have more than five years of experience (I_{33}), highlighting this issue. On a positive note, no workplace accidents were recorded during the assessment period (I_{38}), demonstrating a high level of safety at the facility. Moreover, the absenteeism rate is low (I_{36}). In summary, while the WWTP excels in safety and staff availability, it lacks adequately qualified personnel. Therefore, ONA managers should transition from a focus on quantitative management to qualitative management by providing more training for employees.

The performance of some indicators in criterion 4 (Table 5) has been assessed as insufficient regarding sludge and treated wastewater recovery (I_{43}, I_{44}). The lack of sludge recovery is primarily the absence of effective regulations for energy and agricultural recovery. However, sludge production (I_{41}) is judged acceptable, and sludge dry weight (I_{42}) is considered good. Moreover, an analysis of indicators related to the use of natural resources reveals good energy efficiency regarding the consumption per volume treated based on the TW (I_{45}) and the consumption per BOD_5 removal has high during the assessment period (I_{46}), making energy one of the highest costs in activated sludge treatment

(I_{410}). This increase may be due to excessive aeration based on the influent of organic matter, low pump efficiency, and non-optimised use of energy in the operation of the aeration tank. To address these issues, the ONA managers should focus on optimising by-product management. It is essential to improve the production, treatment, and assessment of energy needs in these processes. Implementing mechanisms for energy recovery and production will be an important step toward enhancing overall performance.

Fig. 5. Overview of PI, criteria, and objective performance

Figure 5 (upper) shows an overview of the WWTP performance and the aggregation value of each criterion (lower). The WWTP obtained the lowest and unsatisfactory performance for criterion 4, with 55.8, followed by criterions 1 and 3, which obtained 74.5 and 74.3. The best performance of the WWTP, with 84.1, was obtained for criterion 2. This tool serves as a guideline for managers to direct and prioritise their improvement efforts, emphasising the need to focus on criteria that exhibit multiple low-performance indicators. In fact, by providing the public with essential information and involving them in the decision-making process, it is possible to strengthen their engagement and initiative, in favour of the proper functioning of the WWTP and protecting the receiving environment as well as the overall environment [25].

6. CONCLUSION

This study proposes a decision support framework to optimise the management of WWTPs. This framework provides the specific needs of ONA managers through a rigorous methodology. It is based on clearly defined objectives, relevant criteria, and PIs adapted to the local context and available financial resources.

The method is illustrated through a case study of the WWTP of Bejaia, Algeria. It enabled the development of a performance assessment system, based on a priority objective: ensuring good management of WWTPs. This objective is supported by 32 performance indicators covering four criteria: environmental protection, quality of service provided to users, human resources management, and recovery of treatment by-products. The results reveal an overall acceptable performance, with a value of 72.2. Three criteria (C1, C2, and C3) show acceptable performance, and criterion C4 shows poor performance, indicating opportunities for management improvement. These results provide valuable insights for ONA managers, helping them identify areas for improvement and intensify their efforts to achieve their objectives.

This study developed the first generation of PIs for WWTPs in Algeria, clarifying the objectives that need to be achieved. During the assessment, these indicators become essential elements for supporting decision-making and monitoring the quality of WWTP management. Their integration opens new perspectives to encourage incentive benchmarking while also promoting continuous improvement in service quality and contributing to a strategy for sustainable management.

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