



Contribution of the requirements engineering to the evaluation of water resources systems efficiency

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Abstract

In the water resources sector, the need to adopt a new way of thinking based on a systemic approach and analysis is justified by several situations: very complex constraints that accompany the development of the sector, functional interactions between various planned developments and the multitude of actors and stakeholders involved. System engineering is a general methodological approach that encompasses all the appropriate activities to design, evolve and verify a system providing an economical and efficient solution to the needs of customers while satisfying the whole of stakeholders. Based on these concepts of size, the purpose of this paper is to apply the principles of systems engineering for the exploration and evaluation of Boughrara water resources system performance. This system located in the north-west of Algeria involves subsystems in constant interaction, namely mobilization, treatment, purification and transfer of water. Its performance takes into account a number of parameters: compliance with customer satisfaction objectives, system constraints, stakeholder role and responsibility for achieving system-wide objectives, and not relationship with sectors of activity.

Keywords Boughrara · Water resources · System · System engineering · Performance

Introduction

The systemic approach has been widely used in many areas: the industry in general, the space, aeronautics, medicine, nuclear, etc., where all the systems have been designed using a systemic approach. In the water resources sector, this approach has rarely been developed, with the exception of a few cases limited to the analysis of the operational safety of complex hydraulic systems. However, it is possible to design, develop and improve the performance of such systems, which, open to their environment, integrate subsystems and elements, often complex, interactive and with multiple feedbacks, in terms of functionality.

The process of systems engineering is a logical sequence of interrelated activities, gradually transforming input elements into output products to achieve the mission or objective of the system (Jackson et al 2010).

We can distinguish, in systemic, four fundamental concepts, namely: the concept of interaction, the concept of totality, the concept of organization and the concept of complexity.

Two approaches are generally adopted for the identification and the analysis of systems: structural view based on a set of constituents (subsystems) in mutual interaction and interaction with the environment integrated according to the mission. Dynamic view based on a sequence of processes (activities, functions) in interaction with the environment chained (coordinates) according to the mission or the results (Grumbach and Thomas 2020).

The systems approach takes a chronological path including the design, feasibility, development, production, use and withdrawal phase of the system. Taking into account the increasing complexity of systems, it is imperative that stakeholders must be involved in the development of the system. This development integrate aspects related to the identification and analysis of needs as the purpose of the system, the involvement of actors and stakeholder satisfaction, technical performance and efficiency measures, analysis of operational requirements and maintenance and finally the implementation of the quality function of the system (Baron and Allegro 2019).

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The decision to implement a system is based on the functional service it brings to its deployment environment. Systems engineering is the basis of this decision reasoning (Ramosaj and Berisha 2014).

The systemic approach based on the functional aspect of systems, whether natural or artificial, is used either for the design of new systems to be implemented or for the analysis of the efficiency of existing systems. This paper, by adopting a systemic approach, aims to analyze the functionality and the performance of water resources system Boughrara on the technical and institutional level.

Application of the approach to the water resources system

The water resources system is a natural and artificial system, open to its environment, dynamic, complex and with feedbacks between its subsystems and elements. The development of relationships and links between technical systems (surface and underground mobilizations, water purification and treatment, protection of ecosystems, desalination and others), the definition of needs and requirements, long-term constraints for disrupting sustainable development and the degree of stakeholder involvement allow to solve, with relevance, all the problems linked to the integrated and participatory management of water resources (Dacko 2009).

In the management of water resources, the systemic concept adds to the concept of "water management" the notions of organization, interdependence, prioritization, coordination and integration (Dobner and Frede 2016).

Due to the large number of multi-sectoral consultations and decisions, variable, depending on the environment, systems engineering tends to search an optimal solution to the water resources system and to optimize planning and strategies in the sector (Datta and Harikrishna 2005).

The systemic approach intended to coordinate the integrated management of water resources for all sectors and interest groups and at different levels: scarcity, excess, floods, siltation, water quality, etc. (Oyebode and Igbi 2018).

The systems analysis, applied to water resources in general, and particularly Boughrara system aims to integrate water resource management in a development policy and a triple mastery of resources, ecosystems and uses. Based on this systemic approach and considering the functional analysis of the Boughrara system, located north-west of Algeria and composed of several water projects, this paper constitutes a multi-criteria study of the performance of the system by requirements correlations at the level of subsystems and its components.

Conceptualization of the Boughrara system

In system engineering, the main mission of the system Boughrara to be analyzed is to produce, quantitatively and qualitatively, water by surface mobilization through the Boughrara dam. These waters will be used for the supply of drinking water, irrigation and ecosystem preservation (Rouissat 2007).

It is composed of interactive subsystems, reflected, projected, conceived and realized in a singular way. The temporal assembly of these subsystems has given rise, in terms of functionality and performance, to a complex global system by the strong interactions of the subsystems below:

Subsystem 1 hydrology of the main and residual watershed affects the inputs of the river, and therefore the quota shares to be allocated to the water transfers planned downstream of the dam, the solid transport coming from watershed affects also the useful capacity of the reservoir and therefore the allocation volumes,

Subsystem 2 the exploitation of the reservoir of the dam is also a parameter to be considered since it may constitute a constraint as to the downstream use of the waters mobilized,

Subsystem 3 the mobilization dam is the core of the system, its response to the various internal and external stresses influences the reliability of the system,

Subsystem 4 the presence of a wastewater treatment plant just upstream of the reservoir, the purified water quality of which affects the overall performance of the system. The various discharges, particularly industrial ones, also have an impact on the quality of the water mobilized and therefore conditioning some criteria of the subsystem transfers downstream of the dam,

Subsystem 5 water transfers to the cities of Oran and Maghnia which are closely linked to the quantitative and qualitative aspect of the waters mobilized at the dam. Water released in the river downstream of the dam intended for the irrigation of agricultural lands of the middle and low Tafna is also conditioned by these two aspects of the water present in the dam reservoir (Rouissat 2016).

Performance evaluation is an essential element of systems steering. The operating safety is inseparable from this performance of the systems. This action aims at managing the requirements of the system during its life cycle. The importance is to highlight the criteria that could compromise the missions of the system and to validate its response to these planned objectives.

The main functions reflect the object of the action of a system. For the application to the system studied, the upstream reservoir and the downstream environment are connected through the structure of the system.

System performance should be analyzed according to the chronology of the process and according to the

hierarchy of the participation of the subsystems and elements of the system in the achievement of its objectives. Figure 1 shows the chronology of the functional process steps of the system to be analyzed.

The exploration and functional identification of the system aims to analyze and manage its requirements during its life cycle, the production of parameters influencing its requirements, the roles of actors and stakeholders and the exploration of evaluation criteria. In a environment that depends increasingly on complex, critical, and intertwined systems, requirements engineering is crucial to developing and preserve safety-critical systems (Martins and Gorschek 2017). Figure 2 shows the schematic exploration of Boughrara system.

Figure 3 shows, in a system engineering approach, the conceptualization of the system in relation to its main mission which is the production of water for various customers.

Typology of the relations between the uses of water resources in Boughrara system

The different users of water have complementary or antagonistic interests and objectives: the support function and that of leisure and tourism are generally complementary while the function of supplying drinking water often clashes with the function of supplying industrial or agricultural water either in terms of quantity and quality. Likewise, the energy function often comes into conflict with that of leisure and tourism or natural environment (question of minimum flows). These antagonisms or conflicts of use are inevitable insofar as the water resource is a system in which all the elements are interconnected. These compatibilities and incompatibilities between the main uses are summarized in Table 1. This assessment of the various relationships (inspired by the work of E. Reynard 2000) of this kind makes it possible to establish the bases for the management of uses by taking care to define orders of priority between the different uses.

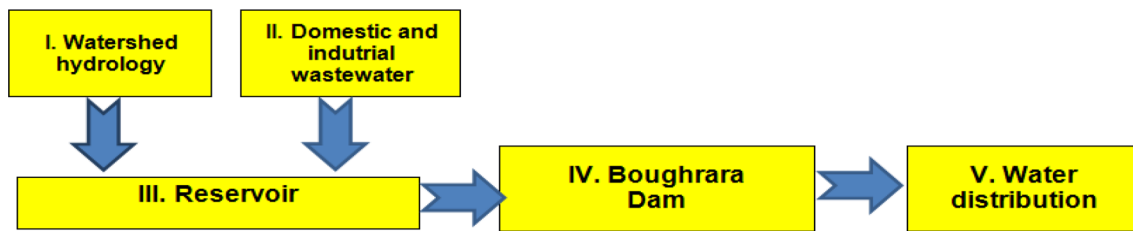


Fig.1 Functional chronology of the system Boughrara

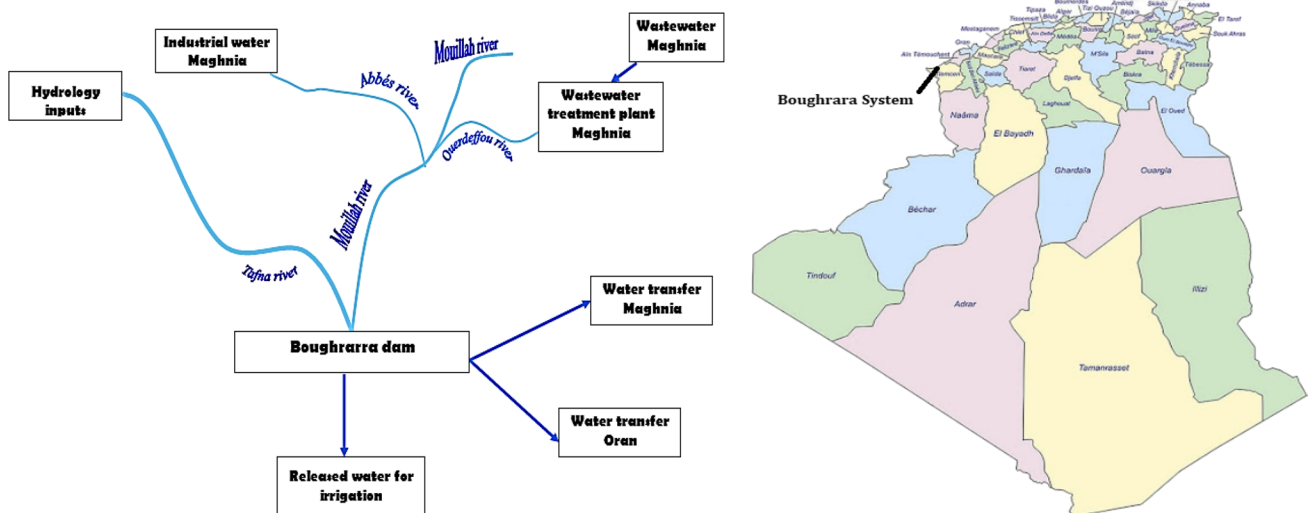


Fig. 2 Schematic exploration and identification of Boughrara system

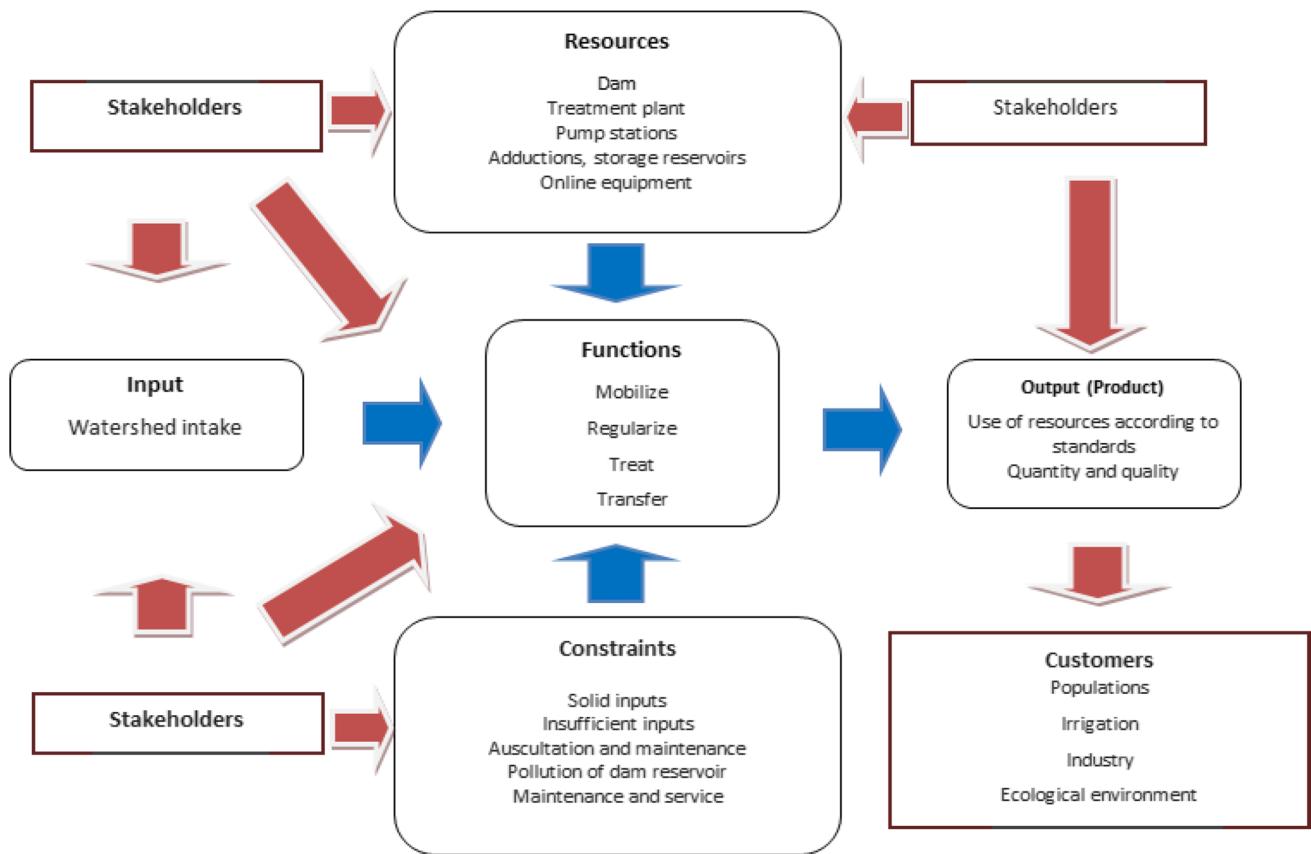


Fig. 3 Conceptualization of Boughrara system

Table 1 Compatibilities and incompatibilities of various types of resource use in Boughrara system

	1	2	3	4	5	6	7	8	9
1									
2									
3					CR	CR		CR	
4									
5			CR			CR		CR	
6			CR		CR			CR	
7									
8			CR		CR	CR			
9									

1. Flood protection
 2. Flow control
 3. Irrigation
 4. Drainage
 5. Drinking water supply
 6. Industrial water supply
 7. Fisheries and the conservation of the natural environment
 8. Pollution problems
 9. Country strategic priorities

CR : Conflict relationships in Boughrara system

Legend

- Interrelations
- Supplementary relationships
- Conflict relationships
- Strategic priorities

At the level of the Boughrara system, and in relation to the uses of the resource mobilized by the dam, four functions come into conflicting situations:

- In terms of satisfaction of needs (quantity of the resource): this concerns the drinking water supply function, the irrigation water supply function and the industrial water supply function.
- In terms of water quality: the function of protection against pollution is in conflict with the functions of drinking, industrial and irrigation supply and is influenced by the quality of domestic and industrial discharges upstream of the dam.

Table 1 summarizes these situations of compatibility and incompatibilities between the main uses of the resource.

Functional analysis of the system

The analysis methods allow the identification of the functions to be insured. They are based on a structured hierarchical, top-down and modular approach. From successive refinements, these methods which rely very often on a

graphic formalism lead to specifications. Each level can then be decomposed by respecting the input-outputs of the higher level. The decomposition continues until the level of detail deemed sufficient for the analysis is reached. The structural aspect refers to the way the system is composed while the functional analysis deals with the purpose of the system.

For the Boughrara system, the resources constitute the inputs from the river to the dam. These waters, in terms of quality, are influenced by the discharges from the treatment plant of the town and industrial units.

The requirements of the system are the quantitative and qualitative satisfaction of the needs for irrigation, drinking water supply and industrial water with regular volumes. The water needs of the different sectors (drinking water, irrigation and industry) are integrated in conflict situations. Pollution of the dam reservoir by upstream discharges greatly influences the objectives of the system.

Also, the actors (different agencies) in charge of management have responsibilities at the level of the subsystems without having a vision of the overall system and its missions.

Functional analysis provides both a technical and a pedagogical method that is part of a rational approach and provides sufficient benchmarks for analyzing, selecting

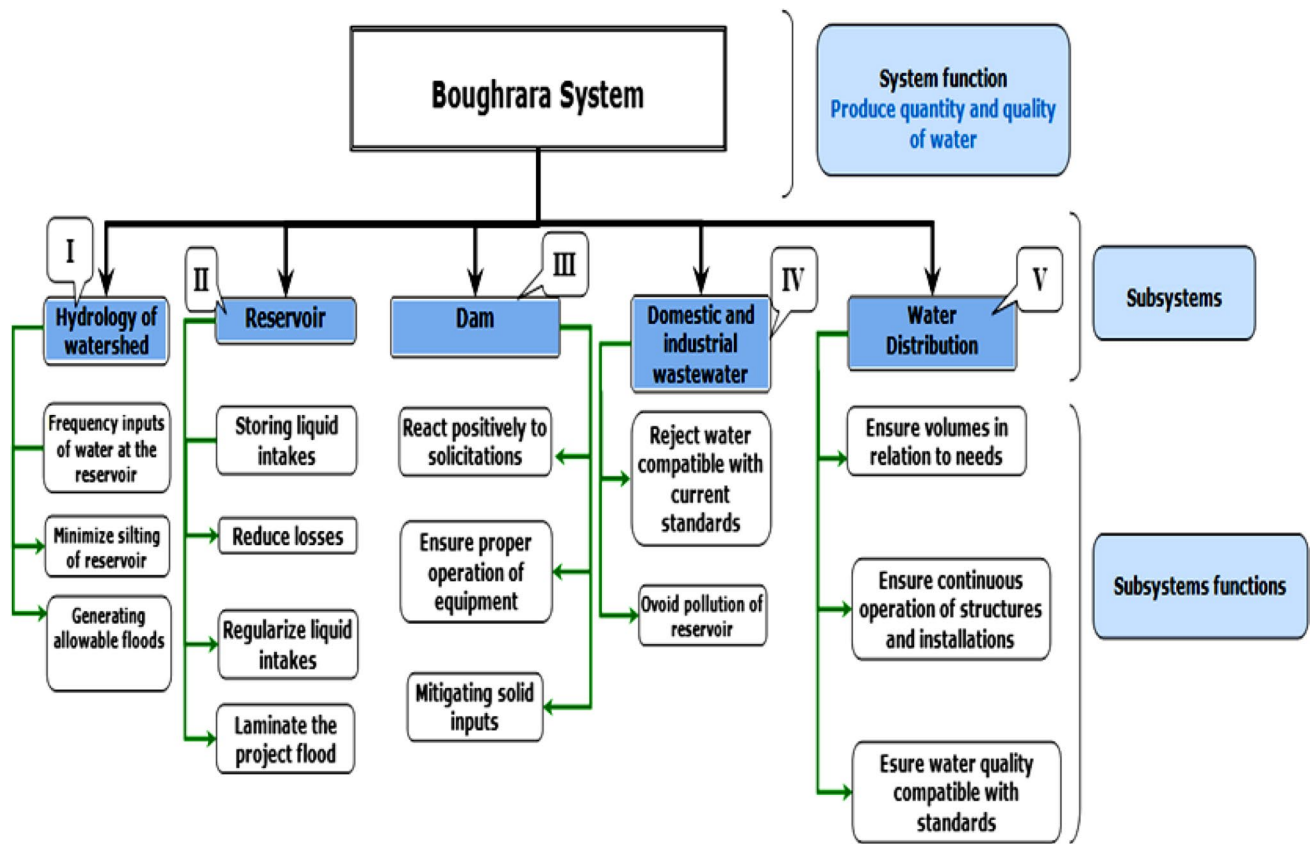


Fig.4 Functional decomposition of the System

and using a system. The subsystems are analyzed by their functionality in a hierarchical diagram. The grouping of functions allows the analysis of allocations (Baron and Allegro 2019). Figure 4 illustrates the functional decomposition of the Boughrara system declined at the scale of the subsystems and the components.

Figure 5 illustrates the functional diagram of the Boughrara system declined at the scale of the components in relation to its main requirements. The results of the functional analysis of the performance of water resources systems offer better results than that based on the physical architecture of the system since it involves the missions of each element in order to achieve the objectives of the global system.

In a functional chronological approach, functional analysis of the system takes into account:

- quantitative and qualitative water inputs to the dam (system inputs).
- the mobilization, regularization, treatment function at the dam level which represents the process of the system
- the water transfer function for drinking, industrial and agricultural water supply.
- the function of protecting ecosystems through the minimum flows to be ensured downstream.

In a system engineering approach, the process (water production) requires resources (the dam, the treatment station, the pumping stations, the supply pipes and the necessary equipment) and records constraints (the transport solid at the dam, inadequate inputs, safety of the dam related to its behavior, possible pollution of the dam reservoir and failure of maintenance). The requirements of the system can be summed up in the satisfaction of water needs in terms of quantity and quality.

Depending on the inputs, resources, constraints and technical requirements of the system, it is imperative to integrate the actors (managers) and stakeholders (users of the system’s product) in its process which constitute the institutional aspect of management of the system.

Hierarchy of Boughrara system requirements

A system must, by its organization, obey to: respond to the needs, expectations and constraints of all stakeholders, be acceptable to and for the environment (physical, social, ecological ...), and represent a globally balanced and optimized solution throughout its life cycle (AFIS 2005). The identification of the influence parameters on the requirements of the Boughrara system must take into account the hydrological

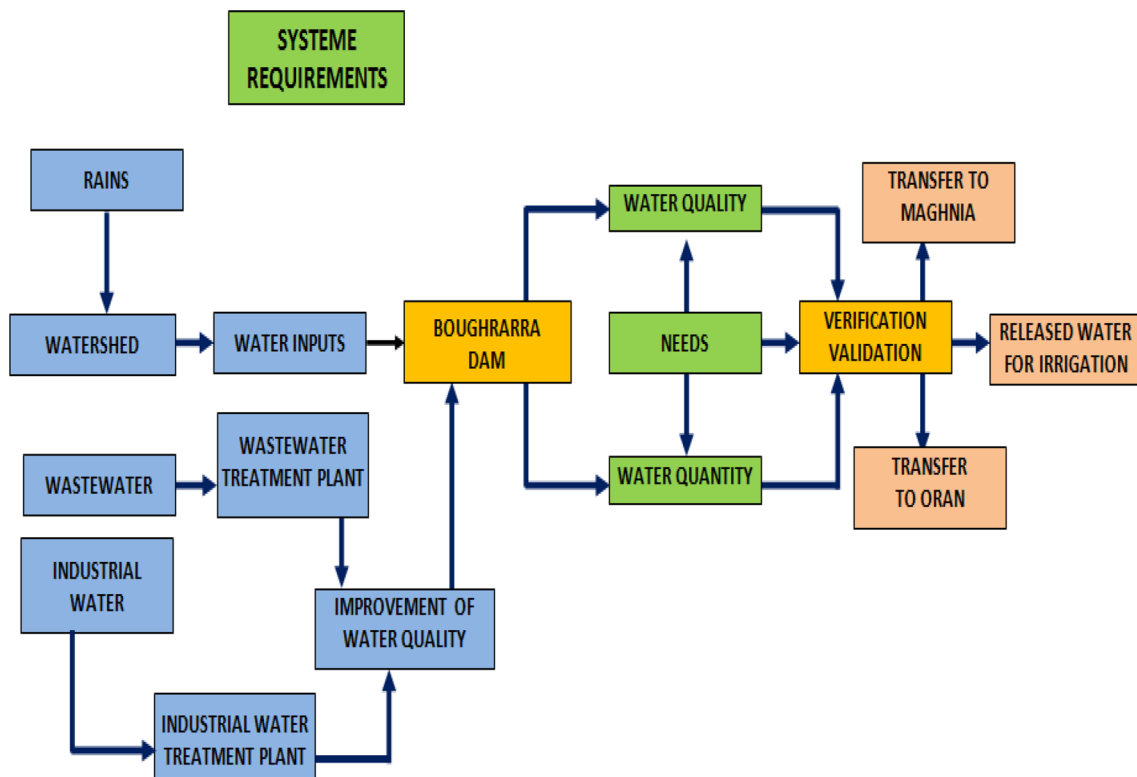


Fig. 5 Functional diagram of the System in relation to its requirements

functions, the technical criteria, flows of water but also the evolution of the water demand (Rouissat 2009).

In addition to the natural parameters, it is necessary to add the anthropic factors and the means of actions of the actors. This refers to the socioeconomic, cultural, institutional, political, regulatory, scientific and technical context (Benblidia 2011).

Figure 6 shows the hierarchy of requirements of the Boughrara system against the supports of stakeholder needs.

System management, definition and roles of stakeholders

Watershed management requires good stakeholder knowledge: those involved in decision-making in watershed-scale water and soil management, and those who will be affected by decisions. Once the context has been analyzed, it is possible to seek to involve in the watershed management the good combination of water actors at the appropriate levels. In order to identify stakeholders involved in

watershed management and those affected by decision-making, it is useful to establish stakeholder support, roles and responsibilities.

Taking both approaches into account, the evaluation of water systems raises two following questions: Who takes part in decision making about the implementation and management of water system? Are all shareholders involved and do they have an equal share in the decision-making progress? (Dobner and Frede 2016).

Figure 7 summarizes stakeholder involvement in the functions of the water resources system at the Boughrara watershed scale.

Constraints and challenges of the system

Factors such as growth and demographic change, economic development and climate change clearly have a major impact on water resources. Similarly, water

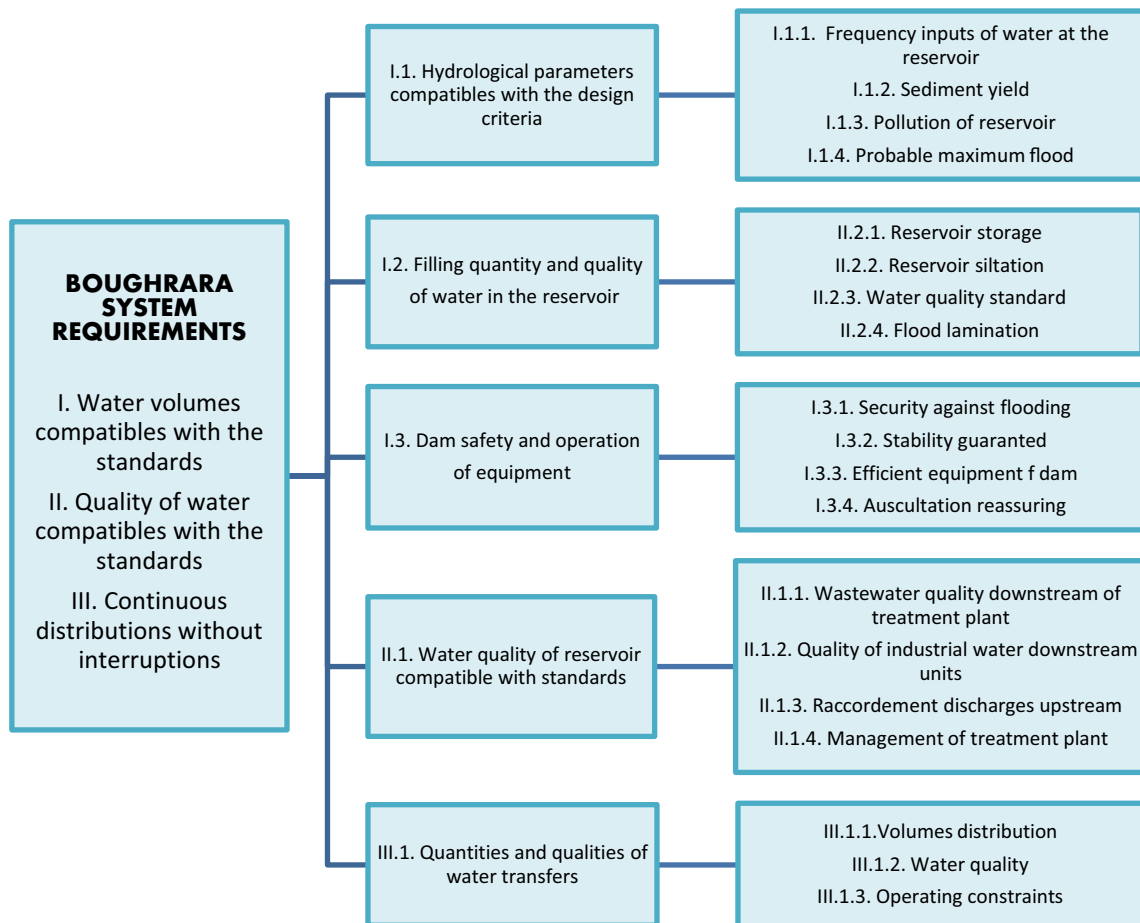


Fig. 6 Hierarchy of Boughrara system requirements

resources have a significant impact on production and economic growth, on health and livelihoods, and on national security. The search for a balance between economic development and preservation of water resources subjects the watershed manager to enormous pressures, risks and conflicts. It is not only water security which influences the achievement in economic growth and human development, but also the level of use of water in different sectors, condition of the water environment and technological and institutional capacities in water sector (Mukherjee 2016).

Table 2 summarizes, for the different functions, the constraints to which the system Boughrara is submitted.

Table 2 Constraints and challenges of the system

Administrative	Coordination of services with the water managers	Coordination with the services of regional planning	Information to the user public
Economic	Offer and demand	Pricing	Users categories and possible conflicts
Cultural	Traditions	Symbolic charge	Irrational behavior
Scientific	Reliability and frequency of measurement on the control network	State of research	Global analysis
Natural	Resources available	Hydrology and hydrogeology	Natural characteristics
Climatic changes			
Social	Demography	Agricultural development	Industrial development
Environmental	Pollution	Erosion	Flow control

Production of evaluation criteria

Water resource management goals in a watershed in relation to sustainable management has as objectives: protecting the quantity of resources, protecting the quality of resources, preserving the health of ecosystems, ensuring socio-economic well-being and applying the principles of good governance (UFM 2013).

Table 3 shows water resources management goals and their associated indicators which can be applied to the Boughrara system.

Table 3 Goals of water resources governance

Goals	Indicators
Protection against exhaustion (Quantity)	Quantity of water available Water consumed Quantitative problems
Protection against excess	Floods probability
Pollution control	Quality problems Vulnerability Contaminated areas
Preservation of ecosystems (Sustainability)	Contribution to base flow of water levels
Socioeconomic well-being	Dependence on drinking water Dependence on agricultural water Dependence on industrial water Efficiency—Use of resources Conflicts of use
Application of governance principles	User Awareness Resource strategy and programs

Evaluation grid of the system

In order to evaluate the performance of Boughrara system, and in addition to the production of the indicators, some criteria must be defined that allow assessment in terms of scoring by assigning ratings relating to the qualitative aspect of the indicators. Table 4 summarizes the scoring grid of the indicators for the evaluation of the system.

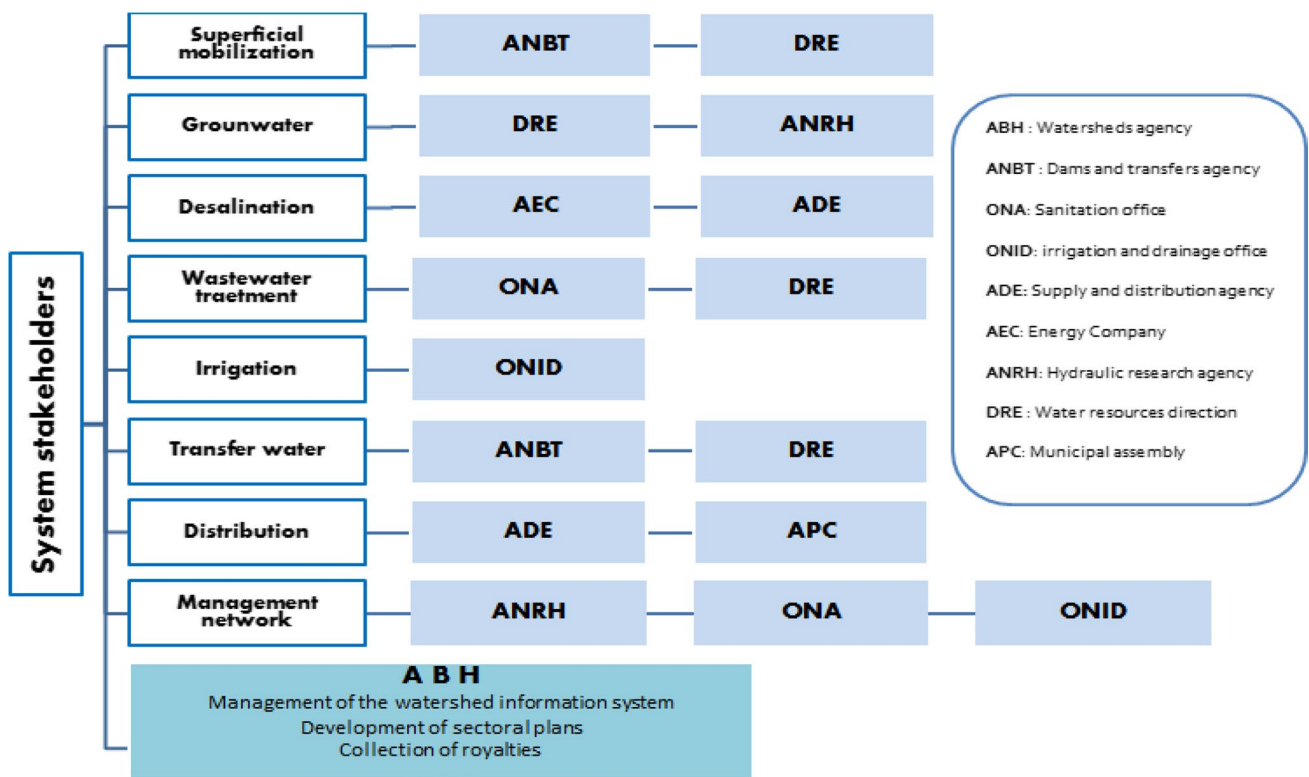


Fig. 7 Roles of stakeholders on Boughrara system functions

Table 4 Rating grid for system evaluation indicators

Indicator response	Rating grid	Symbol
Relevance	Significant, closely linked to objectives	A
	Sensitive to Change	B
	Useful for stakeholders	C
Measurability	Based on available and / or easily accessible data	D
	Efficiency	E
Quality of use	Simple, unambiguous and easy to interpret	F

The evaluation of the system taking into account the production of the indicators, their evaluation and the grading scale requires thorough surveys among the various stakeholders. For this research, the evaluation of the system was done at the scale of the groups of indicators and through survey of management actors which represent the various agencies in charge of mobilizing, purifying and transferring water.

Table 5 illustrates a qualitative summary grid of the Boughrara system at the indicator group level.

Table 5 Scoring grid of system evaluation indicators

Groups of indicators	A	B	C	D	E	F
Availability of water resources	*	*	*			*
Uses and allocation	*	*	*			
Management of water demand	*		*		*	
Water Quality control (Pollution)	*		*	*		*
Evaluation and management of information	*	*	*	*	*	*
Level of water resources governance	*	*	*	*		*

Improved system performance

In the case of the Boughrara system, it is the water supply of the various sectors which constitutes the operational element, that is to say the element which realizes the distribution of waters in order to satisfy the needs. Enabling-products are the means necessary to carry out the operational function of the system but do not participate directly in this function.

To improve system performance, the challenge is to adopt an integrated approach to water resources management by creating an authority to administer the entire river basin and implement a more participatory strategy integrating both uses, users and stakeholders with the different feedback loops. Development of supportable water management strategies includes identification of vulnerability and adaptation possibilities, followed by an effect analysis of these adaptation strategies under different possible futures (Oyebode and Igbi 2018).

Table 6 illustrates the institutional improvements for the integrated management of water resources in Boughrara system.

Table 6 Institutional improvements for the integrated management water resources in Boughrara system

Subsystems	Current actor of management	The need for participatory coordination with	Impact on performance
Hydrology	ANBT	ONA	Protection of the water environment Operation of sanitation infrastructure Fighting all sources of water pollution
		ABH	Managing the information system at the watershed scale
		ANRH	Study of hydrological phenomena Establish and manage a flood forecasting network
Exploitation of the reservoir	ANBT	ONA	Protection of the water environment Operation of sanitation infrastructure Fighting all sources of water pollution

Subsystems	Current actor of management	The need for participatory coordination with	Impact on performance
		ABH	Managing the information system at the watershed scale Collect royalties imposed by legislation
Mobilization dam	ANBT	ANRH	Establish and manage a flood forecasting network
Wastewater treatment plant	ONA	ONID	Management of the operation and maintenance of equipment and Hydraulic infrastructure in irrigation areas
		DRE	Raccordement discharges upstream
		APC	Raccordement discharges upstream
Water transfers	ADE	ANBT	Water quantity in the dam reservoir
		ONA	Water quality in the dam reservoir
		ANRH	Establish and manage a flood forecasting network

Conclusion

The prospective framework for the integrated management of the Boughrara system resulted in the identification of indicators for evaluating the performance of the system linked to compliance with its requirements and their parameters of influence on quantitative, qualitative and sustainable preservation of water. The analysis applied to Boughrara system has revealed interesting results based on a global approach to problems and constraints related to the performance of complex systems. The contribution of the functional analysis led to the definition of the needs

and requirements of the system, in terms of functions and independently of physical choices. The analysis also made it possible to highlight, in a lucid way, the effect of the institutional framework on the functioning and the performance of the system studied and the involvement of all the stakeholders according to the objectives of the system and not in relation to the sectors of activity.

Finally, and based on the analysis of the requirements, the system evaluation indicators were selected and produced by group typology (quantitative availability, uses, resource management, quality and level of governance).

These indicators constitute the dashboard for the governance of water resources at the watershed level and allow the monitoring of system evaluation at the temporal level and the one relating to changes in its environment in order to adapt the process to these changes and ensure the requirements of the various customers of the system and the satisfaction of the stakeholders.

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Compliance with ethical standards

Conflict of interest The authors declare that there is no conflict of interest regarding the publication of this article.

Ethical approval This article does not contain any studies with human participants or animals performed by any of the authors.

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