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IMPLEMENTATION OF THE SYSTEMIC APPROACH AND SYSTEMS ENGINEERING IN THE DESIGN OF SMALL DAMS

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ABSTRACT

Over the past few years, Algeria has embarked on a vast program to build small dams. The small size of dams, the scattered nature of the irrigation schemes, and the randomness of rainfall are among the parameters that motivated managers to implement this resource mobilization strategy. However, the results obtained were not in good agreement with the expected objectives of this program. Indeed, the assessment performed on approximately twenty small dams located in western Algeria showed many shortcomings that were mainly linked to technical design criteria. In addition, these shortcomings were the result of the lack of overall vision and the lack of interaction between the different branches of study of these structures. The systems approach, which is based on the principles of organization, interdependence, prioritization, coordination and integration, in combination with the requirements engineering, can be of great help in ensuring the reliability and good performance for this type of structure. The present paper attempts to address this issue by proposing the implementation of these two principles, namely, the systemic approach and the requirements engineering, for the design of small dams. An analysis is then carried out to address the conceptual aspects of small dams in three distinct zones: the watershed, the dam site, and the downstream zone. The objectives and missions of the system combined with the requirements of the different operators, the functional review of subsystem design, and the elements and components, including the interactive aspect, made it possible, through a multicriteria performance analysis, to produce the correlation matrices of the weighted requirements. The functional decomposition of the system into subsystems and interactive elements has led to the reorientation of the study of its performance with a reliability research approach. The analysis of the system requirements was broken down into sub-systems and components and helped to assess the weights of the various hierarchical needs, at different levels of decomposition. Significant differences were recorded on the weights of the various requirements of the system reflecting its performance and this in the two cases of situation: independent requirements and interactive requirements.

Keywords: Small dams, System, Systemic analysis, Systems engineering, performance.

INTRODUCTION

The northern part of Algeria receives approximately 100 billion m3 of precipitation annually. Approximately 85% of that precipitation volume evaporates, and the remaining 15% is surface runoff, which represents 13.2 billion m^3 of precipitation. In addition, 1.8 billion m^3 of groundwater can be mobilized in the north of the country, and nearly 90% of the volume actually mobilized is used. Therefore, taking into account technically favorable sites (hydrology, topography, geology, etc.), one can say that only six billion m^3 can actually be mobilized (Algerian Ministry of Water Resources, 2021).

Algeria is currently facing an ever-increasing demand for water due to the population growth of the country. In addition, the increase in the water needs of the population, agriculture and industry has particularly been felt in recent years. In addition, the classic means of superficial mobilization of water resources have always been oriented toward large hydraulics, particularly toward large dams. However, the delays in the realization of these works (studies, construction, financing, etc.) have led to a flagrant mismatch between needs and demand (Rouissat, 1999).

In recent years, and under the pressures and tensions generated by a persistent drought, the public authorities have taken actions to efficiently mobilize surface water resources by realizing small dams. This option, which is primarily intended to meet the needs of the agriculture sector, revolves around the following concepts:

Realization rate

Given that the backfill volumes required are not so important, the completion times are generally quite short, which helps to make the precious water resource available to agriculture in a short period of time.

Random climatology of the country

The country's climatology, especially over the past two decades, has experienced significant disruption. We have witnessed long periods of drought interspersed with heavy rainfall.

This system of mobilization of water resources consists of constructing water retention structures that are supposed to be used during drought periods.

Sparse nature of irrigated perimeters

Unlike the large-scale irrigation schemes, which require enormous water mobilizations and transfers, the mobilization of surface water by this type of structure, which is the dam, makes it possible to put precious water reserves at the disposal of the perimeters to be irrigated in a relatively short time (Benlaoukli and Touaibia, 2004).

This type of water resource mobilization allows the rural world, through these small water retention structures, to have access to this precious resource for watering livestock, supplemental irrigation for farmers, etc. For this, reflection and assessment work as well as efficient management, a strategy for these structures is highly recommended (Rouissat, 2010). A retrospective analysis of the results showed that small dams are structures that can play an essential role in the water resource mobilization policy. In addition, small dams are particularly important for the management of semiarid rural areas; they are essential elements for local rural development that are mainly based on irrigation and animal husbandry (US Bureau of Reclamation, 1987).

On the other hand, some shortcomings were noted following the assessment carried out after studies and the construction of approximately twenty small dams in western Algeria. In addition to the limited financial envelope, the design of this type of work was confronted with multiple constraints that are essentially linked to the absence of a global vision of the consistency of studies and to the lack of interactions between the different conceptual branches (Rouissat et al., 2017).

The assessment carried out on approximately twenty structures in western Algeria showed some inadequacies that were mainly attributed to their design, which may be detrimental to the objectives of the construction of these structures (Rouissat, 1999). As such, it is worth citing:

- The lack of an in-depth hydrological study
- The low number of series of measurements,
- Insufficient geological survey of the site
- The lack of details in the geotechnical surveys
- The generalized design in the form of a homogeneous embankments realized with the materials encountered on site, without investigating the design variants

- The spillways superficially dimensioned
- No protection for the spillways and the downstream zone
- The inlet and outlet systems clogged and not working

Therefore, faced with the numerous complex problems associated with the design of these works, a new way of thinking had to be adopted. It should be noted that the systems approach is itself based on systems analysis. This totalizing approach guides the formulation of some operational hypotheses for the construction of indicators and hence seeks to answer certain questions and to provide a number of elements that allow identifying, expressing and prioritizing the problems in a context of interaction and feedback (Bontempi et al., 2008). The different stages involved in the design of small dams are interdependent. It should be noted that the system performance may be compromised by any failure that could occur in a subsystem, an element, or even a component. The present paper aims primarily to study the "Design of small dams" system and to analyze all the requirements regarding the objectives and missions of that system. The main purpose is to carry out a functional analysis of this system by determining the correlations between the requirements of the subsystems and the elements that compose it. Additionally, the aim is to produce a formal, unified and coherent working tool that combines all the study phases and the rules that may be applied during the design phases of small dams.

SYSTEMIC ANALYSIS AND ITS IMPLEMENTATION IN HYDRAULIC INSTALLATIONS

Foundations of the analysis

Systems engineering is an interdisciplinary and combinative approach that progressively transforms input elements into output products for the purpose of achieving the task or goal of the system (Jackson et al., 2010). In general, two methods are followed to identify and analyze systems. The first one is a structural view that is based on a series of mutually interacting constituents (subsystems) and that interacts with the integrated environment, in accordance with the proposed mission. The second one is a dynamic view that is founded on a series of operations (activities, functions) that are in perpetual interaction with the chained environment (coordinates), according to the suggested mission or the expected results (Grumbach and Thomas, 2020).

It is worth indicating that the systems approach allows translating the requirements of a system into design parameters (Dacko, 2009).

With regard to water resource management, the systemic concept provides the water management subject with additional concepts such as organization, interdependence, prioritization, coordination and integration (Dobner and Frede, 2016).

Furthermore, it is noteworthy to mention that integrated water resources management (IWRM) at the watershed scale is a widespread methodological procedure that comprehends the entire activities that are required to design ads to check the efficiency of the water resources system that is expected to provide a technical, economical and efficient solution to meet the needs of customers on the one hand and satisfy the expectations of stakeholders (Rouissat et al., 2021).

It is worth mentioning that a systems approach can transform segmented problems into meaningful opportunities in a holistic view while helping stakeholders to explore and resolve the underlying structural problems related to various constraints (Nandalal and Simonovic, 2003). Moreover, small dam design system requirements can be expressed by a stakeholder (study analysis, project implementation, project management and operation, etc.) or can also be determined by the engineering processes and particularly the study activities. Indeed, each problem generates requirements for a solution. The analyses and empirical results recorded during the investigation are likely to improve and enrich these requirements with the aim of highlighting the criteria that could affect the performance of the mobilization system and subsystems (Bhatia and Mesmer, 2019).

The systemic approach follows a coherent and structured sequence. It is generally viewed as a method that identifies the inputs, processes, outputs and feedback components of a system to design better performing systems (Turner and Baker, 2019).

It is useful to recall that system engineering (or systems engineering) is a global epistemological approach that brings together all the activities that are adequate to design, develop and check a system that could provide an efficient economic solution to meet the client's needs and to satisfy all stakeholders as well (Pinto, 2021). The steps to follow are described below.

- Identification: it consists of collecting and deepening the requirements of stakeholders or others (example: regulatory requirements or technical conditions),
- Analysis: it is about checking the consistency and completeness of requirements, creating models, deducing technical requirements, negotiating requirements with the parties concerned,
- Specification: in this step, the requirements are expressed in a form that is easier to understand by stakeholders and that can easily be used by engineers and other specialists involved in the study, construction and operation of the structure,
- Validation: the requirements must be validated, either in the form of a review of the specifications of a mock-up or of an experimental verification based on a prototype.

The combination of functional analysis with the systems approach

The analysis of the functionality of a system is carried out at the level of subsystems and components. The objective of this approach is to highlight all the interactions that can affect the hierarchy of the functionality for different levels of decomposition of the system. In addition, functional analysis provides a technical and educational method that is part of a rational process for building knowledge; it provides us with sufficient benchmarks to analyze, choose and use a good system (Baron and Allegro, 2019).

Furthermore, functional analysis methods help to develop and propose a model of the operation of a system, also called a functional model of a system, which is in interaction with its different subsystems (Apostolaki et al., 2019).

In addition, functional analysis makes it possible to understand and give a synthetic description of the functioning of the system under study; it also helps to formally and comprehensively establish the functional relationships of the system.

Moreover, the results of the functional analysis of the performance of water resource management systems allow better results to be achieved than those based on the physical architecture of the system because it involves the missions of each element for the purpose of reaching the objectives of the entire system. The main functions clearly indicate the purpose of the action of a system (Brusa, 2018).

Functional identification of the "Design of small dams" system

Functional analysis is defined as the process of transforming system requirements into detailed design criteria, with specific resource requirements at the subsystem and component levels. A function is a specific or discrete action that is required for the accomplishment of a given objective. Obviously, it is important to define how the need should be fulfilled and in what way it should be done. In addition, no element can be determined without justifying it through a functional analysis (Apostolaki et al., 2019).

Furthermore, the functional analysis helps to obtain a good understanding and a synthetic description of the operation of the system under study; it also makes it possible to establish, in a formal and exhaustive manner, the functional relationships of the system and subsystems (Stachtiari et al., 2018). To apply the functional analysis to the study system, i.e., "Design of small dams", the catchment area, the upstream reservoir and the downstream zone must be linked through the system structure based on the operating process. In this case, there is a vertical integration and a transversal integration.

- Vertical integration ensures the simultaneous interconnection between structural identification and requirements identification with functional identification.
- The transversal integration focuses on the connection between the functional identification and the objectives of the system and that of the missions of the system with the satisfaction of stakeholders and the involvement of the actors

concerned by the system. Fig. 1 illustrates these integrations according to a chronological approach.

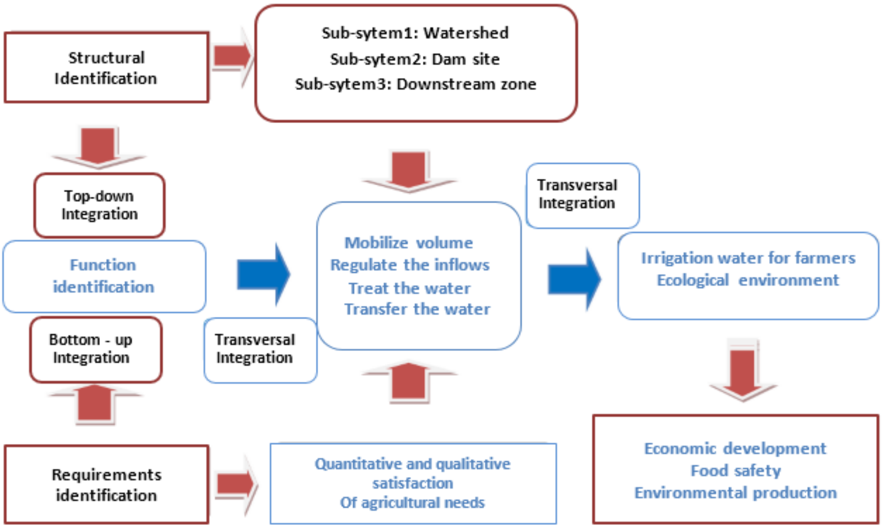

Figure 1: Functional conceptualization of the "small dams system"

FUNCTIONAL ANALYSIS OF THE SYSTEM

It is widely acknowledged that the system can be defined, on the one hand, from the structural elements or subsystems that compose it (structural approach) and, on the other hand, from the functions it performs that's to say functional approach (Potts et al., 2016). For each level of decomposition of the system, the structural elements in turn perform functions that contribute to the achievement of the overall functions of the system. Note that the functions of the system are analyzed in the subsystems and components. The main goal of this approach is to highlight all the interactions that can influence the hierarchy of functions for different levels of decomposition of the system. Fig. 2, given below, clearly illustrates the decomposition of the "Design of small dams" system into subsystems and principal components. A three-level hierarchy was adopted to reduce the complexity of the system. In addition, a more detailed breakdown can be used as part of the system performance analysis.

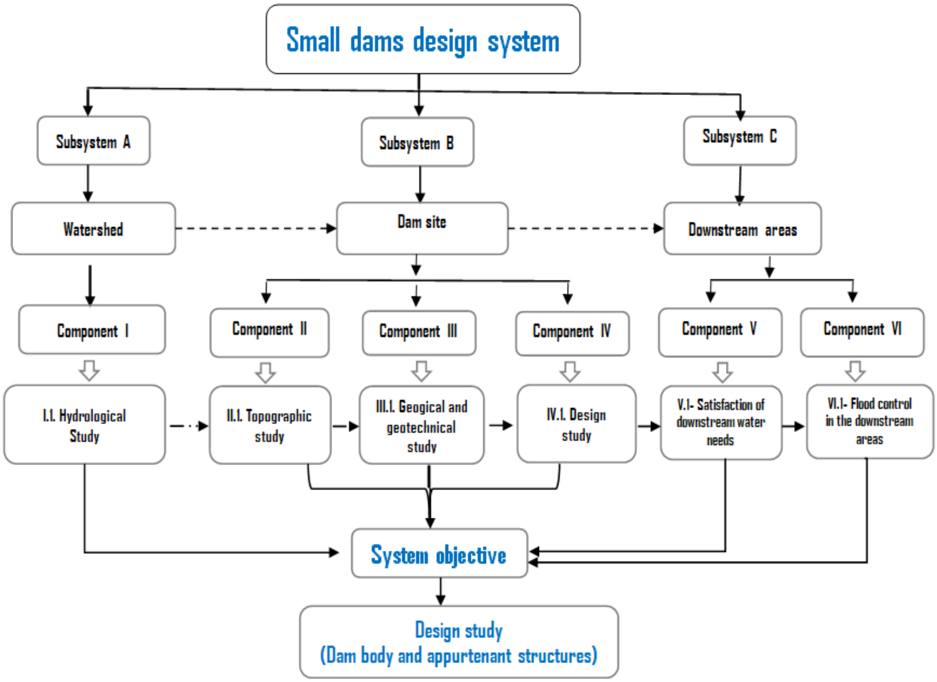

Figure 2: Breakdown of the system into subsystems and principal components

ANALYSIS OF SYSTEM REQUIREMENTS

In the field of engineering, a requirement is defined as a need, a necessity, an expectation that a study, a construction or an operation must satisfy, or even a constraint that has to be satisfied for specific needs. The requirement can be expressed by a stakeholder (analysis of studies, realization of projects, management and operation of projects, etc.) or can also be determined by engineering processes. The functional analysis of system requirements helps to assess the importance of various prioritized needs at different levels of decomposition. This should be done through a comparison of the performance of the system in the two cases: independent requirements and interactive requirements (Haley et al., 2008).

Fig. 3 displays the prioritization of system requirements for the design of small dams.

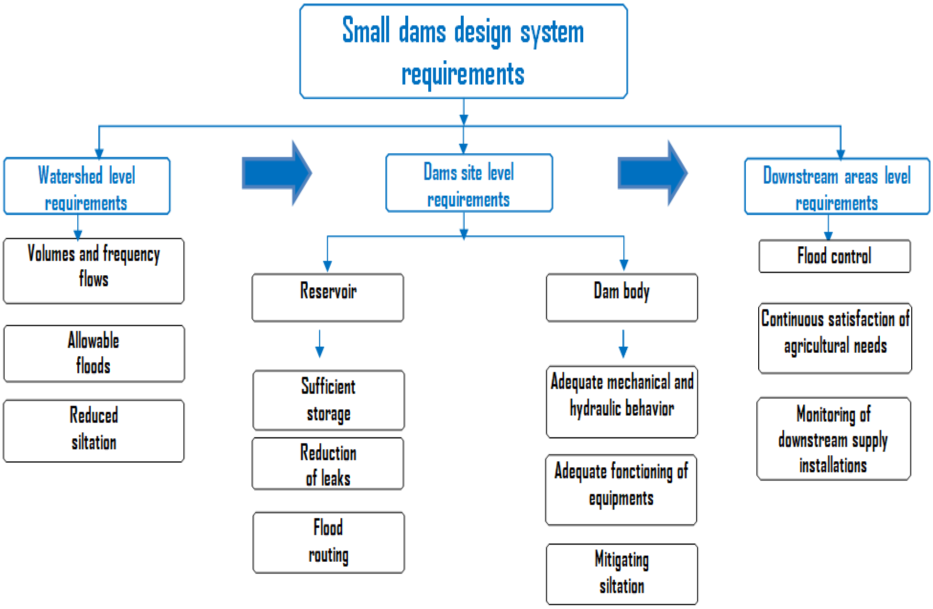

Figure 3: Conceptualization of system requirements

Analysis of the functional requirements of subsystem A

The main objective of the hydrological study of the watershed is to identify the conditions for filling the reservoir, on the one hand, and on the other hand, to estimate the flood against which the dam must be protected and to limit the damage in the downstream area. Table 1 summarizes the main requirements for subsystem A.

Analysis of functional requirements of subsystem B

This phase allows making the most of the natural conditions prevailing on the site (topography, hydrology, geology, geotechnics, etc.) by adopting the best constructive provisions both for the dam and for the appurtenants structures (choice of axes of the various structures). This phase must first select the optimal configuration for each site of the structure based on technical and economic factors and then study the different design variants. Table 2 summarizes the main requirements of subsystem B.

Table 1: Analysis of the functional requirements of subsystem A

Subsystem identification	Component identification	Requirements	
(A) Watershed	(I) Hydrological study	**I.1. Watershed morphology**	
		Physical characteristics of the watershed must comply with the criteria for choosing the dam site	
		a. GRAVELIUS compactness coefficient (K_c)	$1.2 < K_c < 3$
		b. Global slope index (I_g)	$2\% < I_g < 5\%$
		c. Slope of main river (I_P)	$0.5\% < I_P < 7\%$
		d. Specific height difference (D_s)	$50 < D_s < 100$
		e. Drainage density (D_d)	$1.2 < D_d < 1.4$
		f. Runoff coefficient (C_R)	$0.2 \leq C_R \leq 1$
		g. Runoff speed (V_R)	0.3 (m/s) $< V_R < 0.9$ (m/s)
		I.2. Hydrological parameters	
		- Average annual inflows A_{av} Important to fix the total volume of the reservoir and the total regulated volume	- Average annual inflows A_{av} complies with the filling volume of the reservoir and the needs to be met
		- Inflows frequency A_U Important for setting the holdback adjustment volume and the normal holdback dimension (NRN)	- Inflows frequency A_U that comply with the following criteria: - Regulation volume - Operating volume
		- Solid transport regime (A_s) (m^3/km^2/year) Important to fix the dead volume $V_{(dead)}$ of the reservoir, and the water intake level.	- Inflows Solid A_s $100 \leq A_s \leq 350$ Slightly erodible land
			Abrasion rate T_a (t/km^2/year) $130 \leq T_a \leq 2300$
			- Sediment load $D_c < 50$ kg/m³
			- Runoff coefficient C_{er} $0.4 \leq C_{er} \leq 0.6$
			- Bedload global solid transport rate T_c $0.10 A_S \leq T_c \leq 0.15\ A_S$

Table 2: Analysis of the functional requirements of subsystem B

Subsystem identification	**Component identification**	**Requirements**	
(B) Dam site	(II) Topographic study	II.1. Watershed morphology	- Storage capacity compatible with downstream needs - Significant flood capacity
		II.2. Valley morphology	- Shape of the valley with reduced backfill volumes - Cross-sectional profile without any instability risk - Choice on stable and watertight surroundings - Downstream wave propagation without major damage - Installation of appurtenant structures with reduction of work volume
		II.3. Borrow areas for materials	- Availability of construction materials near the dam site - Sufficient quantity of materials - Quality of materials compatible with design criteria
	(III) Geological and geotechnical study	III.1. watershed site	- Risk of minor leaks - Acceptable instability risks - Admissible and economically favorable foundation and waterproofing conditions
		III.2. Area occupied by the embankments and foundations	- Acceptable and economically favorable foundation and waterproofing conditions
		III.4. Borrow areas for materials	- Materials can technically and economically be utilized - Characteristics compatible with the dam design - Hydraulic, mechanical and chemical characteristics favorable to embankments design
	(IV) Design study	IV.1. Dam design variants	- Stability of dam body and its foundations ensured - Watertightness of dam body and its foundations ensured - High economic feasibility
		IV.2. Spillway design variants • Frontal type spillway • Lateral type spillway	- Topography and geology perpendicular to the axis of the structure are favorable - Evacuation of the project flood - Flood evacuation ensured - Restitution of downstream flows without major damage - Economic feasibility of the structure design ensured
		IV.3. Bottom outlet and intake system	- Temporary diversion during works without major risks and economically feasible - Reduction of dam siltation - Emptying operation guaranteed in the event of an incident - Continuous supply of the downstream areas as needed - Dam stability ensured in the event of rapid emptying - Preventive lowering of the water level ensured

Analysis of the functional requirements of subsystem C

The study of the impact of the project on the downstream area is a regulatory procedure that aims to examine the insertion of the project in its entire environment while investigating the direct and indirect effects. In addition to the satisfaction of the downstream agricultural needs, this area must be analyzed in the event of normal operation of the structure or in the case of dam failure. Table 3 summarizes the requirements for this subsystem.

Table 3: Analysis of the functional requirements of the upstream zone - Watershed

Subsystem identification	Component identification	Requirements	
(C) Dam site	(V) The reservoir used as needed	V.1. Meeting downstream needs	- Water volumes distributed according to fixed standards - The quality of water complies with standards - Continuous downstream supply
	(VI) Protection against potential floods	VI.1. Flood control in the downstream areas	- Project flood wave propagation with favorable restitution downstream - Reduced human and material losses in the event of dam failure - Preservation of the ecological environment downstream

The characteristics of the requirements analysis of the small dam design system require specific analysis of the relationship between the study and the project.

The functional analysis of requirements develops the design functions that are performed by the dam components. For this, it was decided to carry out a structural analysis while considering all the constituent components involved in the dam development, then to position these components with respect to the objective of the system, and finally to determine their interactions with other components.

PRODUCTION OF PERFORMANCE MATRICES

A function is defined as a specific or discrete action that is necessary for the accomplishment of a given objective. It is used to identify "What" and not "How" (i.e., "What needs to be accomplished" versus "How it should be accomplished"). No one denies that to identify and develop a product, it must first be justified through a functional analysis.

The different stages that are essential to the realization of the performance matrices are then considered by taking the example of meeting requirements specifications for system performance criteria. In this case, one has to:

- Evaluate and weight the degree of contribution of each characteristic to meeting needs,
- Analyze the contribution of the characteristics through a qualitative judgment,
- Prioritize characteristics.

The relationships between "What" and "How" are generally defined using an interaction scale that involves four forms: Strong, Moderate, Weak, and absent. When a "How" element responds directly to a "What" element, the interaction is said to be strong. On the other hand, if a quality characteristic does not meet the needs, then the relationship between “What” and “How” is a weak or even nonexistent interaction. The purpose consists of setting a target for each characteristic. It is therefore necessary to draw up the list of elements involved in the technical description and possibly prioritize the quality characteristics. It should also be noted that the relations between the different characteristics can be determined, which results in the interaction between the "What" and the "How". This can be done by proceeding as follows:

- Evaluate the degree of interrelation between the characteristics of the product (see if two characteristics conflict or are redundant),
- Analyze the interrelationships,
- Highlight the necessary communication links between the different units seeking to develop the system.

Part of the performance matrices is based on the interactions between the elements of "How", with the following modalities: Very positive, Positive, Negative, Very negative and Nonexistent**.**

Fig 4 illustrates the analysis of the functional correlation matrix for the design of a small dam system.

The functional correlation matrices can be used to represent the relationships between system requirements and functional requirements of subsystems with different levels.

The functional correlation matrix should indicate the level used in the functional hierarchy during the preparation of the matrix. A summary of the functional performance matrix analysis is detailed in Table 4.

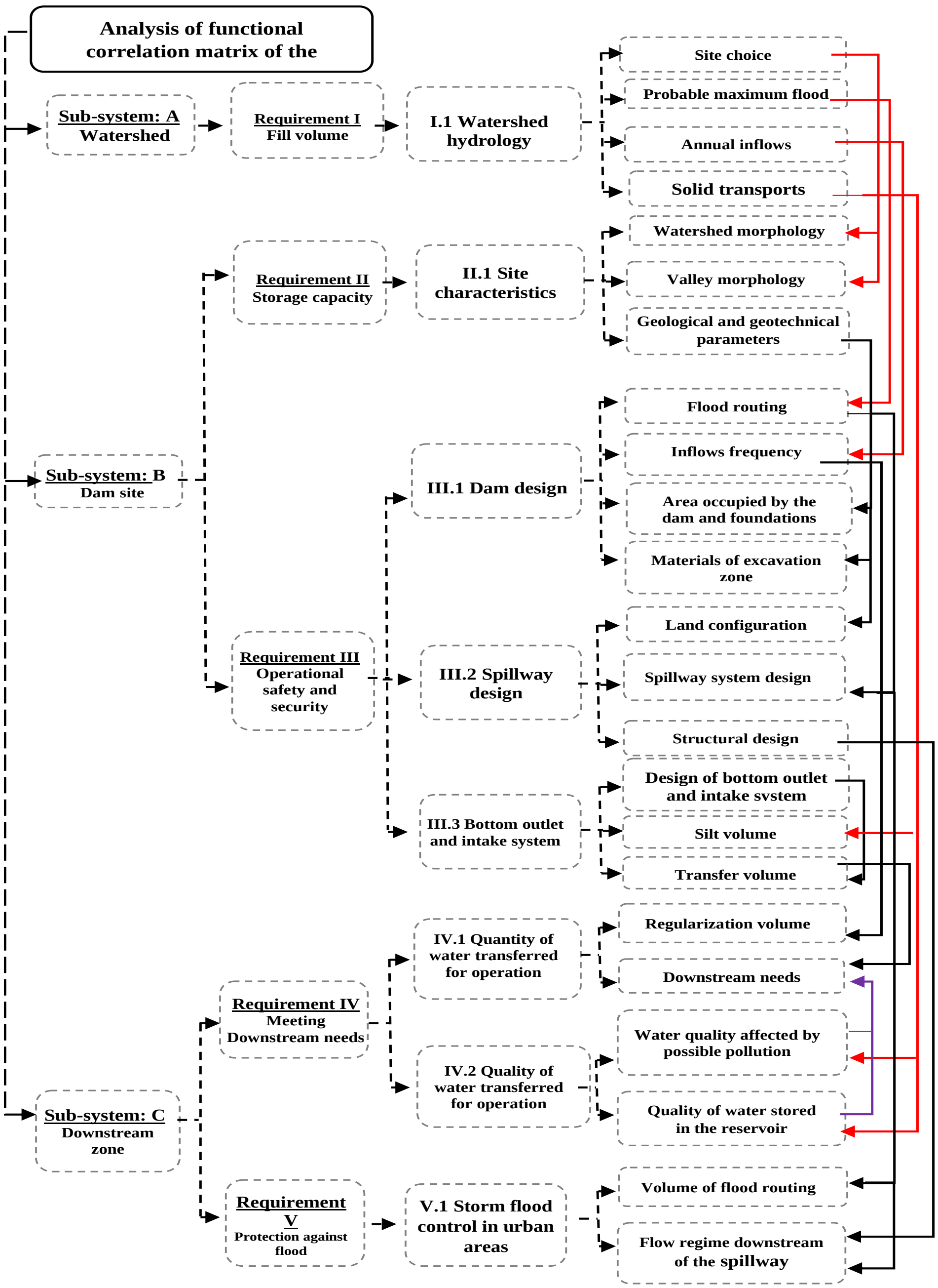

Figure 4: Analysis of the functional correlation matrix for the design of a small dam system

Table 4: Summary of the analysis of the functional performance matrix of the system

System requirements	Functional requirements for level 1	Functional requirements for level 2
I - Fill volume	I.1 Watershed hydrology	I.1.1 Choice and location of dam site I.2.2 Possible maximum flood I.2.3 Annual inflows I.2.4 Solid transport
II- Storage capacity	II.1 Site characteristics	II.1.1 Basin morphology II.1.2 Valley morphology II.1.3 Geological and geotechnical parameters
III- Operational safety and security	III.1 Dam design	III.1.1 Flood routing III.1.1 Inflows frequency III.1.2 Dam footprint and foundations III.1.2 Materials making up excavation zone
	III.2 Spillway design	III.2.1 Land configuration III.2.2 Spillway system design III.2.3 Structural design
	III.3 Bottom outlet and intake equipment	III.3.1 Design of intake and discharge system III.3.2 Transfer volume III.3.3 Silt volume
IV- Meeting the downstream needs	IV.1 Quantity of water transferred for use	IV.1.1 Regularization volumes IV.1.2 Downstream needs
	IV.2 Quality of water transferred for use	IV.2.1 Quality of water possibly affected by pollution IV.2.2 Quality of water stored in reservoir
V- Protection against floods	V.1 Storm flood control in urban areas	V.1.1 Volume of flood routing V.1.2 Flow regime downstream of the spillway

Subsequently, it is necessary to balance the weights of the different elements making up the system. This operation was carried out in close consultation with the stakeholders in charge of studies of small dams and those who are supposed to use the system. A satisfaction rate of 60% of the agricultural needs was decided and fixed by the stakeholders who were in charge of using this system. Tables 5, 6 and 7 show the list of small dam design requirements and their weights and the list of functional requirements for the first and the second levels, respectively.

Table 5: List of small dam design requirements and their weights

X (i)	System requirement	Weight
X (1)	Fill volume	90
X (2)	Storage capacity	80
X (3)	Structure safety	70
X (4)	Meeting downstream needs	60
X (5)	Protection against floods	50

Table 6: List of functional requirements of level 1

Y (i)	Functional requirements of level 1	Weight
Y(1)	Watershed hydrology	90
Y(2)	Site characteristics	80
Y(3)	Dam design	70
Y(4)	Spillway design	80
Y(5)	Bottom outlet	60
Y(6)	Quantity of water transferred for use	80
Y(7)	Quality of water transferred for use	70
Y(8)	Storm flood control in urban areas	70

Table 7: List of functional requirements for the second level

Y(i)	Functional requirements of level 2	Weight
Y1	Location and choice of dam site	70
Y2	Possible maximum flood	80
Y3	Annual inflows	80
Y4	Solid transport	60
Y5	Watershed morphology	70
Y6	Valley morphology	60
Y7	Geological and geotechnical parameters	60
Y8	Flood routing	70
Y9	Inflows frequency and their regularization volume	60
Y10	Dam footprint and foundations	50
Y11	Materials of the excavation zone	60
Y12	Spillway system design	60
Y13	Land configuration	40
Y14	Structural design	60
Y15	Intake and bottom outlet system design	70
Y16	Transfer volume	70
Y17	Silt volume	60
Y18	Stored volume	70
Y19	Downstream needs	50
Y20	Water quality affected by possible pollution	50
Y21	Quality of water stored in the reservoir	60
Y22	Volume of flood routing	80
Y23	Flow regime downstream of the spillway	60

METHODOLOGY FOR THE MATRIX ANALYSIS OF THE FUNCTIONAL CORRELATION OF THE SYSTEM

The next step consists of determining the degree of correlation between the main elements of rows and columns. Typically, three to four levels of correlation are used; they are represented by specific symbols (Table 8); the symbolism adapted by Cohen was adopted. In the case where no correlation exists, the corresponding box in the correlation matrix is left blank.

Table 8: List of weighted correlations

Strong correlation	10
Moderate correlation	5
Weak correlation	1
Zero correlation	0

The next step consists of establishing the different weighted interactions between the different "What" (X variables) and "How" (Y variables) to identify the mutual influences and their degree of intensity. Table 9 presents the reading grid of a correlation matrix.

Table 9: Correlations between variables X and Y (requirements and functions of level 01)

System requirements			Function Y(i) - Level 1							
			Y(1)	**Y(2)**	**Y(3)**	**Y(4)**	**Y(5)**	**Y(6)**	**Y(7)**	**Y(8)**
X(1)	Requirement I	90	×	×	×	×	×	×	×	
X(2)	Requirement II	80		×	×	×	×	×		×
X(3)	Requirement III	70	×	×	×	×	×			×
X(4)	Requirement VI	60	×					×	×	
X(5)	Requirement V	50	×	×	×	×	×			×

The method for calculating each "How" (element of each column) consists of taking the sum of the products of the weights of each "What" and the value assigned to the correlation (0, 1, 5 or 10) and then dividing the total by 100 (maximum scale value for the example used).

Once these calculations are completed, the weight values reported in Table 10 are then added at the bottom of the correlation matrix.

Table 10: Quantified correlations between the quantities X and Y with the weight of "How" - Level of decomposition 1

System requirements			Functions Y(i) - Level 1							
			Y(1)	**Y(2)**	**Y(3)**	**Y(4)**	**Y(5)**	**Y(6)**	**Y(7)**	**Y(8)**
X(1)	Requirement I	90	10	5	5	10	1	5	1	
X(2)	Requirement II	80	0	10	5	1	5	10		1
X(3)	Requirement III	70	5	5	10	10	10			5
X(4)	Requirement VI	60	5					10	10	
X(5)	Requirement V	50	5	5	5	10	5			10
Function weight for level 1			18	18.5	18	21.8	14.4	18.5	6.9	9.3
Maximum weight values Y(i)			9	8	7	21	7	14	6	5

Similarly, the same procedure is repeated again for level 2 regarding the system requirements. Tables 11 and 12 give the quantified correlations between the quantities X and Y, as well as the respective weights of "How".

Table 11: Correlations between the variables X and Y (requirements and functions of level (2)

Functions Y(i) - Level 1	Weight	Function Y(i) - Level 02																						
		Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9	Y10	Y11	Y12	Y13	Y14	Y15	Y16	Y17	Y18	Y19	Y20	Y21	Y22	Y23
Y(1)	90	×	×	×	×																			
Y(2)	80	×				×	×	×			×							×	×	×				
Y(3)	70						×	×	×	×	×	×						×						
Y(4)	80		×			×			×				×	×	×									×
Y(5)	60				×											×	×	×		×				×
Y(6)	80			×		×				×						×	×		×	×				
Y(7)	70			×	×													×		×	×	×		
Y(8)	70	×	×		×				×				×					×					×	×

Table 12: Quantified correlations between the quantities X and Y, with the weight of "How" - Level of decomposition 2

Functions Y(i) - Level 1	Weight	Function Y(i) - Level 02																						
		Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9	Y10	Y11	Y12	Y13	Y14	Y15	Y16	Y17	Y18	Y19	Y20	Y21	Y22	Y23
Y(1)	90	10	10	5	5																			
Y(2)	80	5				10	5	10			5							5	5	5				
Y(3)	70						10	5	5	10	1	5						5						
Y(4)	80		10			1			10				10	5	5									5
Y(5)	60				5											10	5	5		1				1
Y(6)	80			1		5				10						5	5		5	1				
Y(7)	70			1	1													1		1	10	10		
Y(8)	70	5	5		5				10				5					5					5	10
Function weight - Level 2		16.5	20.5	6	11.7	12.8	11	11.5	18.5	15	4.7	3.5	11.5	4	4	10	7	14.7	8	6.1	7	7	3.5	1.6
Maximum weight values - Y(i)		9	17	4.5	11	8	7	8	15	15	4	3.5	8	4	4	6	7	14	8	4	7	7	3.5	7

RESULTS AND DISCUSSION

The identification of the mutual influences and their degree of intensity makes it possible to quantify the degree of correlation between the elements relating to the degrees of achievement of the objectives of the system through its subsystems and components. This action also allows the evaluation of the weights of the system requirements taking into account the presence or not of the different interactions.

For both scenarios (structural or functional reasoning), the variation of the allocation scales on the weights of the different system requirements can be determined. Functional analysis emphasizes the dynamic relationships that exist between the internal components of the system. These dynamic relationships of transactions and exchange also exist between the system and its environment. The system can no longer be considered a closed system, but must be analyzed as an open system. The interaction between objectives means and environment requires an adaptation of both their structure and their mode of operation.

In the approach adopted for the studies of small dams, this notion of interaction between the elements of the system and its environment is often overlooked and the approach is generally singular.

Figs. 5 and 6 illustrate the variations in the weights of the different system requirements for the two levels of system decomposition, namely:

- Unambiguous requirements: the weight of "How" considered without mutual interactions of the requirements of the different elements of the system,
- Interactive requirements: the weight of "How" considered with mutual interactions of the requirements of the different elements of the system.

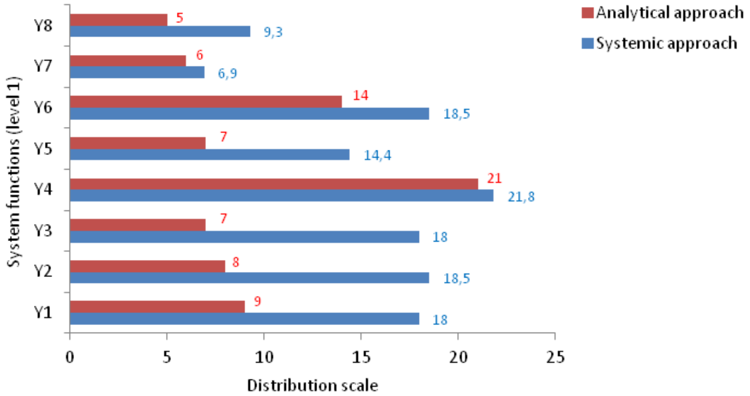

Figure 5: Impact of the allocation scale on the weight of functions - Level 1

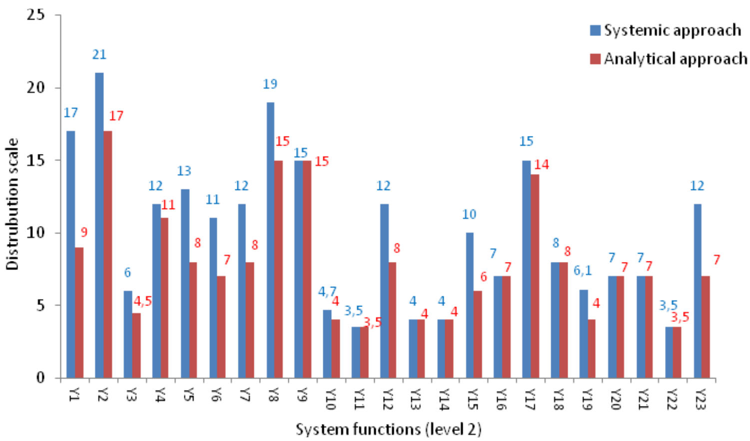

Figure 6: Influence of the allocation scale on the weight of functions - Level 2

By considering the influence of the allocation scale on the weight of functions illustrated in Figure 5 and Figure 6 for the two levels of decomposition, we see that the relative differences in the impacts of the attributes of the system on the weights of the functions are significant between the analytical and systemic approach and are related to the degree of decomposition of the system in functional mode. Table 13 gives the relative deviations assessed for the some components of the system compared between the architectural and functional approach of the system.

Table 13: Relative deviations of functional requirements between analytical and systemic approach

Y (i)	Functional requirements of level 1	Relative deviation (%)
Y(1)	Watershed hydrology	50
Y(2)	Site characteristics	56
Y(3)	Dam design	61
Y(5)	Bottom outlet	51
Y(8)	Storm flood control in urban areas	46.5
Y (i)	**Functional requirements of level 2**	**Relative deviation (%)**
Y1	Location and choice of dam site	47
Y2	Possible maximum flood	20
Y5	Watershed morphology	38
Y12	Spillway system design	33
Y15	Intake and bottom outlet system design	40
Y19	Downstream needs	34
Y23	Flow regime downstream of the spillway	41.66

CONCLUSION

The application of systemic analysis principles to the small dam design system had the merit of helping to apprehend the complexity of the system with respect to the objectives set. The prospective framework of the approach led to the identification of indicators to be used in evaluating the performance of the system with regard to compliance with its requirements. From the systemic analysis, it emerged that the weighted prioritization of the system and subsystem requirements with regard to the allocation scale can be utilized in setting the actions to be carried out at different levels to avoid elementary failures that could induce a request for information about the overall system performance. Moreover, the complexity of the system, its strategic nature in developing the agricultural sector, and the requirements to meet needs require prior anticipation of the analysis for the success of these systems. This success certainly depends on the level of performance evaluation, at the level of subsystems, elements and components, and at the level of the overall system**,** which is itself influenced by the elements that compose it. The functional breakdown of the system into subsystems and elements has the merit of reorienting its performance study with a more reliable research approach.

Furthermore, the analysis of the system requirements helped to assess the weights of the different prioritized needs at different levels of decomposition, with a comparison of the performance of the system in these two cases: independent requirements and interactive requirements. This requirement analysis also led to a good assessment of the influence of the requirements on the allocation scale. The participation rates of each requirement, at different levels of decomposition, to system performance were assessed using the multicriteria performance analysis.

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