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Use of structural systems analysis for the integrated water resources management in the Nenetzingo river watershed, Mexico

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ABSTRACT

Currently, many parts of the world are facing challenges resulting from poor water quality and water scarcity. To achieve water sustainability under this scenario, the main causes of water problems must be addressed while simultaneously dealing with their consequences. The development of a systemic perspective of water management is vital for facing such challenges. Integrated water resources management (IWRM) is one approach that analyzes water management from a systemic perspective, and structured systems analysis is a generalized and complementary approach that can facilitate the analysis of water management systems. The objective of this study was to perform a structural analysis of the water management system of the Nenetzingo River watershed (Mexico), with the goal of providing strategic and tactical guidance for the integrated water resources management of the watershed. Thus, in this study, a structural analytical method (cross-impact matrix multiplication applied to classification [MICMAC]) and a strategic planning perspective were employed. Modifications to the MICMAC method were necessary to comply with the objectives of the present study, leading to the proposal of an enhanced MICMAC method, denominated *e*-MICMAC. Overall, 49 variables were identified as relevant to the water management system of Nenetzingo, of which eight strongly influence the other variables and 10 are dependent on the dynamics of the system. In addition, nine variables serve as links between the influential and the dependent variables, while 18 variables were unable to be clearly characterized. Finally, three variables were excluded from the systems analysis without impact. Of the total variables, 22 were found to be essential to the system's dynamics and were considered key variables. These key variables were then used to provide strategic and tactical guidance for the IWRM of the study basin. In conclusion, the structural analysis approach enabled the structure of the studied system to be elucidated. The variables that constituted the system were determined in addition to their relationships of influence or dependence. Lastly, the complexity of the analysis was reduced through the determination of key variables. The present structural analysis represents an important tool for achieving the sustainability of water resources in the Nenetzingo watershed and can strengthen planning measures in both the short and the long term while facilitates the definition of scenarios for the implementation.

1. Introduction

1.1. Current challenges for water management

In 2013, according to the Global Water Partnership (Global Water Partnership (GWP, 2014), 770 million people worldwide lacked access to improved drinking water sources, and 2500 million people lacked access to adequate sanitation. Furthermore, 75 per cent of wastewater was incorporated into natural run-off without adequate treatment. As a partial consequence, 35 million people each year are currently expected to experience premature death as a result of water-related diseases. During this century alone, economic losses due to flooding and drought have reached approximately 1.9 billion dollars.

Lalika et al. 2015 considered that failed policies have prevented the proper governance of water and watershed conservation. For this reason, the authors argued that attention should be placed on the development of capacities for water management among interested stakeholders, on the promotion of hydrological services and on the

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improvement of living conditions for local communities located within watersheds. In addition, Franzén et al. 2015 recommend promoting greater participation of stakeholders with interest in water governance and management of hydrological watersheds. However, during the identification of stakeholders, those related to all aspects of water management should be considered and not solely the water authorities or the users with the greatest weight in decision making.

Up until the end of the past century, water management throughout the world was predominately concerned with satisfying demand. The apparent sufficiency of water supplies did not oblige a more in-depth analysis of new water sources or their exploitation. Nonetheless, the insufficiency of water supplies has become more notable in recent times, leading to the search for new management regimes to govern this vital resource. This search has highlighted that an efficient management of water demand considers factors and actors that are involved, from those related with natural water storage to the end users. Efficient management practices, for example, may aim to reduce the vulnerability of the water supply in the face of abundance or scarcity or to recycle used water back into the water supply.

In light of this new scenario, the application of a systemic perspective has gained popularity. This perspective represents one means of taking into account the variables related to the efficient management of resources. Accordingly, the use of different methods and instruments that facilitate systemic analysis has increased. In particular, during water management planning, the consideration of components of a water system would enable a more sustainable and holistic management of the system, thereby leading to an improvement in the living conditions of the served population in social, economic and environmental terms.

The objective of the study presented herein was to analyze the water management system of the Nenetzingo River watershed, with the goal of providing strategic and tactical guidance for the integrated management of its water resources.

1.2. Experiences in structural systems analysis

According to Godet (1994), the main objective of structural analysis is to identify the structure of the relationships among the variables that characterize a system. This type of analysis allows for a generalized representation of a studied system, and, afterwards, the complexity of the initial representation may be reduced through the identification of its essential variables, denominated key variables.

The antecedents of structural analysis are diverse. Although structural analysis has been used in distinct fields such as social studies, software development, supply chain analysis, and manufacturing systems, it has not been applied in the context of IWRM. Therefore, the current study is based on the antecedents of this method being applied to different aspects of territorial management.

Estuardo-Cevallos et al. (2015) used the MICMAC (cross-impact matrix multiplication applied to classification [Godet, 1994]) method of structural analysis to identify the most influential components of environmental management in the administrative region of La Concordia (Ecuador), with the goal of guiding a more strategic management. Among the results, the authors differentiated the variables of the system according to certain planning thresholds or the time frame in which they should be addressed in the short, medium and long term. In addition, several useful variables were identified for assessing interventions to the system. Meanwhile, Delgado-Martínez and Pantoja-Timarán (2015) aimed to identify the key variables that influence the regional system of Ruta del Oro (Colombia). To achieve this, the authors used a MICMAC analysis (Godet, 1994) to categorize the variables influencing the system and, similar to the previous study, their planning thresholds.

In another study, Corral-Quintana et al. (2016) proposed a method for guiding strategic decision making based on a systemic rather than fragmented perspective in order to mitigate the desertification process in the Canary Islands, Spain. Structural analysis and the MICMAC method were also applied as tools for identifying the relationships between the variables of the system as well as the key variables of the system. Lastly, system modelling tools were used in order to better understand the dynamics of the system and to analyze different scenarios (according to qualitative information about the tendencies of the variables).

These antecedents discussed demonstrate that structural analysis has proven utility for supporting decision making. Even so, the selection of the representative variables of a system, the identification of the key variables and the interpretation of the results should not be performed according to fixed schemes but should depend on the system under study, the planning focus and the desired scope of the corresponding courses of action (Aledo et al., 2008; Ambrosio-Albalá et al., 2011; Delgado-Serrano et al., 2015; Estuardo-Cevallos et al., 2015; Delgado-Martínez and Pantoja-Timarán, 2015).

This previous idea leads to the main limiting factor of structural analysis: subjectivity in the selection of variables and in the evaluation of the relationships between them (Aledo et al., 2008; Delgado-Serrano et al., 2015; Delgado-Martínez and Pantoja-Timarán, 2015). Since this analysis is based on the use of qualitative data, users must have adequate knowledge of the system at hand, and involved stakeholders must be dedicated to participating in the analytical process (Ambrosio-Albalá et al., 2011).

However, these same characteristics enable structural analysis to be a participatory tool. A common vision of the analyzed system may be constructed by the actors participating in the decision-making process, fostering a collaborative environment (Ambrosio-Albalá et al., 2011; Delgado-Serrano et al., 2015). In addition, this tool represents a practical approach particularly, but not only, when statistical information on relevant variables is scarce (Ambrosio-Albalá et al., 2011; Corral-Quintana et al., 2016). Furthermore, upon identifying the key components of a system, this type of analysis aids in the reduction of a system's complexity. Interventions to the key components of a system may thus be identified and prioritized. Finally, the time thresholds for which a system will continue to function can be highlighted, thus informing the time frame for when necessary interventions to the system will need to occur (Ambrosio-Albalá et al., 2011; Delgado-Serrano et al., 2015). Clearly, structural analysis does not substitute decision-making processes but rather serves to compliment and to strengthen them (Estuardo-Cevallos et al., 2015).

2. Conceptual theoretical framework

2.1. Integrated water resources management

Integrated water resources management (IWRM) is one framework for the sustainable management of water. The Global Water Partnership (GWP) is one of the main international groups that has adopted this perspective, defining it as an approach to help "manage and develop water resources in a sustainable and balanced way, taking account of social, economic and environmental interests" (GWP and INBO [International Network of Basin Organizations], 2009, p. 10). One fundamental aspect of IWRM is its systemic focus, in which multiple water uses are considered as interdependent. Under this focus, to achieve integrated management, all water uses must be contemplated as whole (Cap-Net et al., 2005).

In Mexico, the implementation of IWRM as a framework for water management is outlined by the National Water Law (ley de aguas nacionales in Spanish), which was passed in 1992 yet has experienced more recent reforms dating to 2016. The guiding framework of this law is sustainable development, in which IWRM is established as a "priority and issue of national security" (Congreso de la Unión, 2016, p. 10).

2.2. Structural systems analysis

According to Godet (1994), “a system is represented by a group of interrelated elements” (p. 73). However, “a [model of the] system is not reality but rather a means (for the human spirit) to observe it” (Godet, 1994, p. 98). To this, we could add that systems analysis is a way of thinking in order to identify and to understand a system that aims to represent reality.

Godet (1994) further describes the structure of a system as a network of relationships between its components. An analysis of these components allows the evolution of a system to be comprehended. Therefore, structural systems analysis can be described as a systematic method of analysis of the relationships between the constitutive variables of a studied system and of its explanatory environment. This method has the objective of highlighting the main influential and dependent variables and, as a consequence, the variables essential to the evolution of the system (Godet, 2009).

Arya and Abbasi (2001) highlighted that, in theory, all components of a system should be considered during analysis, yet, in practice, this is not possible given that the behavior of some components is not easy to determine or significant to the system as a whole. Furthermore, analyzing all components is highly demanding in terms of time and resources.

In agreement with Godet (1994) and Delgado-Martínez and Pantoja-Timarán (2015), structural analysis is used to identify the key variables of system, which helps to achieve two goals. The first goal is to contribute toward decision making with respect to a specific objective, as structural analysis enables the identification of interceding variables and actors. The second goal is to inform the prospective process, or the reflection upon possible future scenarios and the identification of the key variables that would configure those scenarios.

The phases of structural analysis are listed at following: (1) inventory of the variables, (2) description of the relationships between variables and (3) identification of the key variables (Godet, 1994, 2000 and 2009; Godet and Durance, 2011). In the first phase, a list of internal and external variables that characterize a studied system and its environment is elaborated. Each variable should be described, conceptualized and detailed within the framework of the objectives for analyzing the system. The second phase involves the determination of the relationships among the identified variables, which are analyzed and discussed, and, ultimately, a consensus on these relationships is established. In the final phase, the essential variables, or the key variables for analyzing and understanding the evolution of the system, are determined.

There are two key concepts in structural analysis: driving power (or influence) and dependence. According to Delgado-Martínez and Pantoja-Timarán 2015, “driving power is the influence that a variable exercises over other variables. . . Dependence is the impact of certain variables on one in particular, or subordination to the impact of the rest” (Delgado-Martínez and Pantoja-Timarán, 2015, p. 29). For Godet (1994), the behavior of the influential variables conditions a system to a great extent, while the dependent variables respond more sensitively to the evolution of a system.

3. Study area

The Nenetzingo watershed is a microwatershed of 37.6 km^2 located within the southeastern portion of the State of Mexico. At the municipal level, the watershed spans the northern and northeastern portions of the municipality of Ixtapan de la Sal and the central-western portion of the municipality of Villa Guerrero, covering a surface area of 29 km^2 (77.1%) in the first municipality and 8.6 km^2 (22.9%) in the second (Fig. 1).

Several aspects have drawn attention to the water management of the Nenetzingo River watershed. The 14 localities of the basin have been categorized as rural with medium and high levels of marginalization. Furthermore, the scarcity of water and sanitation services in this zone represents a challenge to the entities responsible for providing such services, including municipal, communal and private entities. Alternative solutions are necessary to improve the provision of water and sanitation services. Currently, in the best scenario, water is distributed to household cisterns or tanks, although wastewater is not treated. Morbidity as a result of acute diarrheal disease is one issue that requires particular attention.

4. Material and methods

The procedures followed in this study to perform a structural systems analysis of the water management of the Nenetzingo River watershed were based on a comparative analysis of relevant studies by several authors (Aledo et al., 2008; Ambrosio-Albalá et al., 2011; Arya and Abbasi, 2001; Delgado-Martínez and Pantoja-Timarán, 2015; Delgado-Serrano et al., 2015; Estuardo-Cevallos et al., 2015). The steps can be summarized in the three phases proposed by Godet (1994, 2000 and 2009) and Godet and Durance (2011), which were presented in Section 2.2 and are also described in greater detail in the following subsections.

4.1. Inventory of variables

The phase of creating an inventory of the variables began with semi-structured interviews, which were carried out with delegates from the localities of the watershed. The delegates are informed of the problems facing their locality and are able to relay those issues to the relevant municipal authorities for consequential action. Water issues were evidently part of the current municipal agenda.

The content of the semi-structured interviews was based on a previous characterization of the overall study area (documentary, in-the-field research based on statistical data and analysis). Delegates were asked to identify water challenges (problems) in their locality with respect to domestic, agricultural and environmental water uses. Then, for each water challenge identified, the delegates indicated the potential causes and consequences of each challenge as well as any actions undertaken for solving these challenges. The interview design was based on a root cause analysis (Okes, 2009; McMahan, 2011).

In the first part of the root cause analysis, the common water challenges of the localities were integrated. Challenges mentioned in only some of the localities were also included, assuming that issues particular to one locality could potentially be present in other localities although not yet recognized. For each water challenge, all causal and consequential responses were considered, as well as solutions, integrating the common responses and annexing those particular to certain localities. From these groups of responses, a list of variables characterizing the water management system of the Nenetzingo River watershed was formulated.

In structural systems analysis, the definition of the variables that form part of a process is one preliminary requisite for evaluating the relationships among the variables. Evaluators should concur upon the definition of these variables within the context of the specific system that is being evaluated. For example, with respect to water quality, interviewees commonly mentioned that agrochemicals are used on crops in the watershed or that domestic wastewater is dumped into runoff without receiving adequate treatment.

4.2. Description of the relationships among variables

The second phase was performed with the support of a MICMAC software (Godet and Bourse, 2004). The first step of this phase was to evaluate the relationship among the variables. For this evaluation, the support of subject-area experts from academic and governmental sectors was requested. Specifically, six researchers from the field of integrated water management (including the authors of this document) in

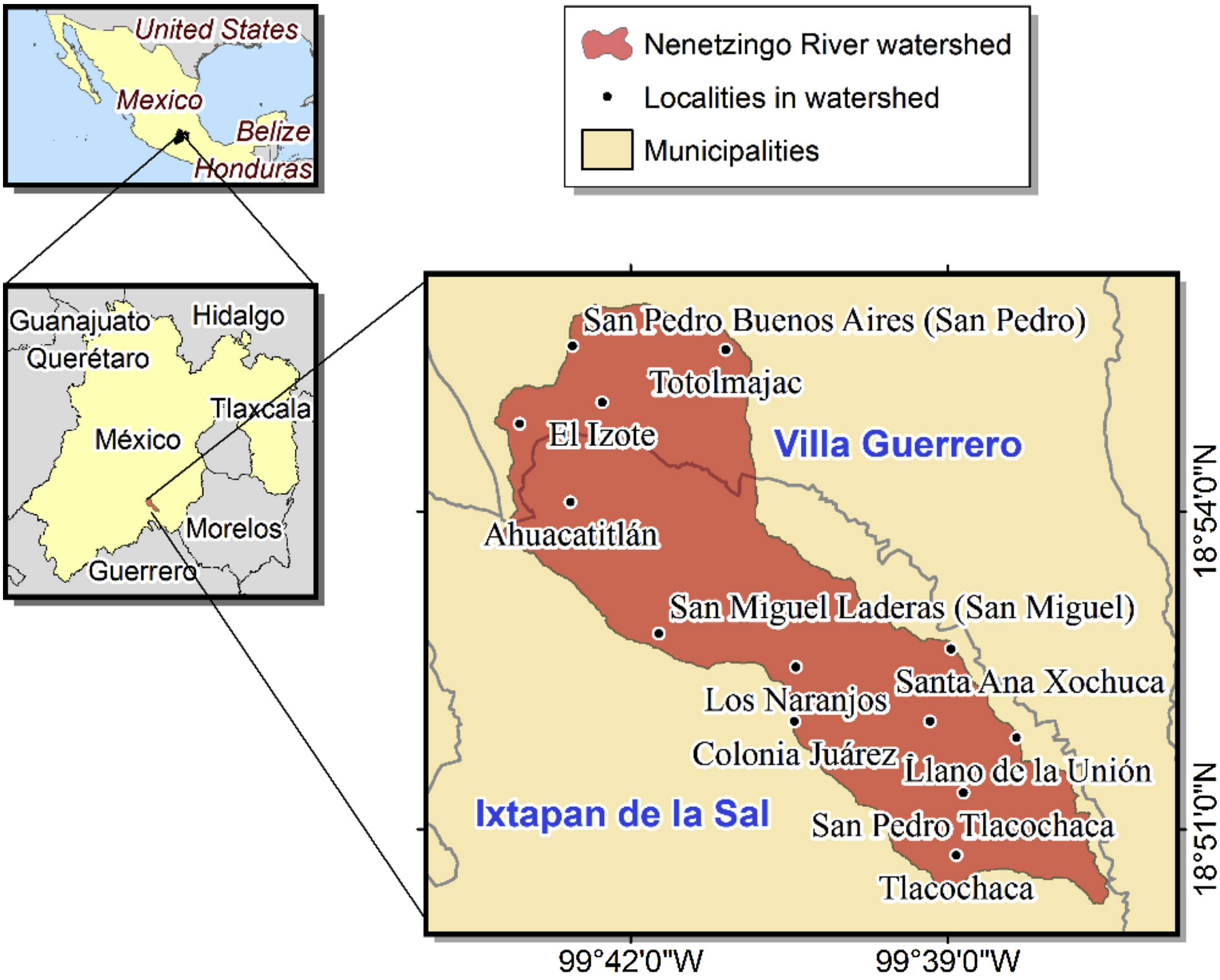


Fig. 1. Location of the Nenetzingo River watershed.

addition to one representative from the municipal water authority participated in this step.

The experts evaluated the relationships between the variables of the water management system of the watershed using a *structural analysis matrix* (Godet and Durance, 2011). The rows and the columns of the matrix arranged the variables to facilitate pairwise evaluations. In each case, experts were asked if a change to a first variable (listed in a row) would cause a direct change to the second variable (listed in a column). Each variable identified in the interviews was evaluated with respect to the rest of the variables, resulting in a total of 2352 evaluations.

Based on the proposal of Godet (1994) for filling out the structural analysis matrix, if the response is affirmative, then the number one is placed in the corresponding cell. In contrast, if the response is negative, then the relationship is graded as zero. This logic was used for two main reasons. This evaluation was first meant to highlight the existence of an influential relationship between variables without focusing on the magnitude of the relationship. This reduced disparities in the discussion as to whether or not one variable influences another and also initially avoided the subjective discussion of the degree to which one variable influences another. The second motivation was related with the time frame of tactical planning (short term), and, therefore, potential relationships (in the long term) were not of interest. The result of this step was a matrix of direct influence (MDI).

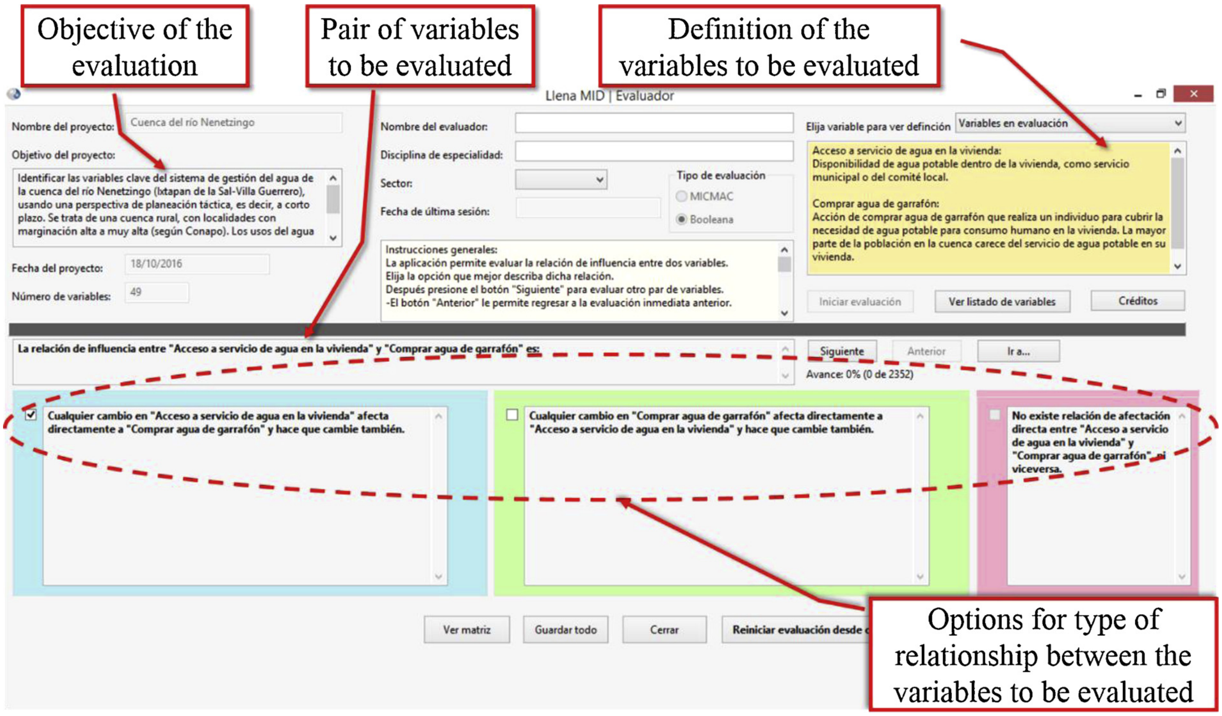
In order to reduce the complexity of filling out the MDI, it was developed and used an informatics application called *Llena MID* (Fig. 2), which was used to present the comparisons to the evaluators, who were informed of the objective of the evaluation, the variable pair to be evaluated and the definition of each variable. The exercise was placed within the framework of the specific case under analysis.

An MDI was obtained for each evaluator. The evaluations for each possible relationship of direct influence were integrated into a single matrix, applying the rule of majority vote. Afterwards, following the MICMAC method, the integrated MDI was elevated to the fifth power, or until the hierarchies of influence and dependence were stabilized (Godet, 1994). The result of this operation was the matrix of indirect influence (MII) for the variables describing the water system of the Nenetzingo River watershed.

Once the MDI and MII were generated, these were integrated into a matrix of total influence (MTI) outside of the MICMAC software (Godet and Bourse, 2004), as the software did not provide a function for integrating these matrices. The present authors propose the MTI as a complement to the MICMAC analysis. This revised procedure is labelled as *e*-MICMAC, or enhanced MICMAC. At following, the steps taken to generate the MTI are detailed.

For this integration, first, the MII was standardized by dividing the values of the cells by the highest value contained in the matrix, generating a matrix with values ranging from zero to one. This new matrix was denominated MSII (matrix of standardized indirect influence) (Eq. (1)). Afterwards, the MSII was summed with the MDI (Eq. (2)) in order to generate the MTI, indicating whether the relationship between the variables was direct (values zero or one), indirect (values between zero and one) or both (values greater than one). The value of the sum indicated the magnitude of the relationship.

$$a_{i,j} = \frac{b_{i,j}}{Max} \tag{1}$$



Nombre del proyecto: Cuenca del río Nenetzingo

Objetivo del proyecto:
Identificar las variables clave del sistema de gestión del agua de la cuenca del río Nenetzingo (Ixtapan de la Sal-Villa Guerrero), usando una perspectiva de planeación táctica, es decir, a corto plazo. Se trata de una cuenca rural, con localidades con marginación alta a muy alta (según Conapo). Los usos del agua

Fecha del proyecto: 18/10/2016

Número de variables: 49

Nombre del evaluador:

Disciplina de especialidad:

Sector:

Fecha de última sesión:

Tipo de evaluación
○ MICMAC
● Booleana

Instrucciones generales:
La aplicación permite evaluar la relación de influencia entre dos variables.
Elija la opción que mejor describa dicha relación.
Después presione el botón "Siguiente" para evaluar otro par de variables.
-El botón "Anterior" le permite regresar a la evaluación inmediata anterior.

Elija variable para ver definción: Variables en evaluación

Acceso a servicio de agua en la vivienda:
Disponibilidad de agua potable dentro de la vivienda, como servicio municipal o del comité local.

Comprar agua de garrafón:
Acción de comprar agua de garrafón que realiza un individuo para cubrir la necesidad de agua potable para consumo humano en la vivienda. La mayor parte de la población en la cuenca carece del servicio de agua potable en su vivienda.

La relación de influencia entre "Acceso a servicio de agua en la vivienda" y "Comprar agua de garrafón" es:

Avance: 0% (0 de 2352)

☑ Cualquier cambio en "Acceso a servicio de agua en la vivienda" afecta directamente a "Comprar agua de garrafón" y hace que cambie también.

☐ Cualquier cambio en "Comprar agua de garrafón" afecta directamente a "Acceso a servicio de agua en la vivienda" y hace que cambie también.

☐ No existe relación de afectación directa entre "Acceso a servicio de agua en la vivienda" y "Comprar agua de garrafón", ni viceversa.

Fig. 2. Informatics application *Llena MID* for filling out the matrix of direct influence (Manzano-Solís et al., 2016).

where:

a = cell of the matrix of standardized indirect influence;

b = cell of the matrix of indirect influence (result from elevating to the first power);

i = matrix column with values of 1, 2, 3, …, n;

j = matrix row with values of 1, 2, 3, …, n;

n = number of variables in the system;

Max = cell with the maximum value in the entire matrix of indirect influence.

$$c_{i,j} = d_{i,j} + a_{i,j} \tag{2}$$

Where:

c = cell of matrix of total influence;

d = cell of the matrix of direct influence.

4.3. Identification of key variables

In the MTI, the indicators of influence and dependence were calculated, considering that the sum of the values of a row indicates the level of total influence (or driving power) that a variable has within the system (Eq. (3)), while the sum of the values of a column signals the level of total dependence of a variable with respect to the system (Eq. (4)).

$$I_j = \sum_{i=1}^{n} e_i \tag{3}$$

Where:

I = indicator of the total influence of the variable in row j;

e = cell of the matrix (MDI, MSII or MTI).

$$D_i = \sum_{j=1}^{n} e_j \tag{4}$$

Where:

D = indicator of the total dependence of the variable in column i;

Following the foundations of the MICMAC analysis (Godet, 1994), the values of dependence were considered as the x axis and the values of influence as the y axis in order to graph the influence-dependence relationship of the variables. The midpoints for dependence and influence were identified, and from their intersection, four quadrants were generated in order to classify the variables according to influence-dependence relationships.

To define the band that delimited the middle-clustered variables, the data classification method of goodness of variance fit (GVF) was used (Environmental Systems Research Institute [ESRI], 2016). The principle behind classification by GVF is that groups of data (classes), or variables, at the interior of a grouping will have a greater degree of similarity and will differ more with respect to variables belonging to other classes (ESRI, 2016). In Eq. (5), the expression for calculating GVF is presented.

$$GVF = \frac{SDAM - SDCM}{SDAM} \tag{5}$$

Where:

$SDAM$ = sum of squared deviations for array mean;

$SDCM$ = sum of squared deviations for class means.

Eqs (6) and (7) describe the calculation of the SDAM and SDCM values, respectively.

$$SDAM = \sum_{i=1}^{n} (x_i - \bar{X})^2 \tag{6}$$

$$SDCM = \sum_{i=1}^{n} (x_{i,h} - \bar{X}_h)^2 \tag{7}$$

Where:

x = value i of the dataset;

n = data total;

X^{-} = average of the dataset;

h = 1, 2, 3, …, m;

m = total classes;

The value of GVF varies between zero and one. Values near one are ideal, as they indicate better fit.

To apply the GVF, the data should be ordered in ascending hierarchical form, and the number of classes into which the data will be divided should be established. The search for optimal class limits is a cyclical process. An initial GVF calculation is performed, and some data is moved from one class to another to recalculate the GVF with new classes and compare them with those of the previous calculation. This process occurs successively until achieving a GVF that cannot be improved and, to the extent that is possible, that generates a value near one.

In this study, three categories of influence and three categories of dependence were delimited using GVF. The three categories were high, medium and low, as the objective of the structural analysis was to discover the most influential and the most dependent variables as well as the midpoint between them or, in other words, the variables that did not completely adjust to either of the extremes.

The GVF classification method was used to classify the data into three categories of influence and three of dependence and to enable the interior of each category (high, medium or low) to be similar to the greatest extent possible and also differentiated with respect to the rest of the groups. This operation provided the minimum and maximum limits of each class, enabling the zones of high and low influence and of high and low dependence to be defined as well as the mid-zones of influence or dependence. The values that delimited the classes of mid-influence and mid-dependence were also used to define the limits of what were labelled as middle-clustered variables.

Once the variables were categorized, the key variables become apparent. The key variables are those that allow for the complexity of the system to be reduced, given a large number of involved variables, yet conserve a structure that enables the system dynamics to be analyzed. For Godet (1994), the key variables are the most influential variables in the system or the most dependent on the system dynamics. In this scenario, the middle-clustered and excluded variables together with the variables that express average influence or dependence in the outside of the middle-clustered zone may be dismissed. Due to their nature, these uncharacterized variables were excluded from the system.

In order to identify the variables corresponding to average influence and/or dependence, the zone of the uncharacterized variables was extended toward the superior and right-hand portion of the graph, highlighting the zone of average conditions of influence and/or dependence. Therefore, the key variables of the system under study are those that remained outside of this zone.

4.4. Strategic and tactical orientation for the IWRM

As the last step of the procedure, the key variables were identified for their capacity to inform strategic and tactical planning in the Nenetzingo River watershed. As the objective of IWRM is to promote the best living conditions for the local population, the key resultant variables that would express this scenario were also identified. Based on these variables, preventative and reactive actions may be carried out in order to attend to the causes and the consequences, respectively, of water-related challenges and to maintain adequate living conditions, as expressed by the resultant variables. Thus, this analysis connects preventative actions with the intermediate variables. Finally, in applying the same logic, the key input variables were identified. Preventative actions with respect to the input variables may be taken to ensure appropriate values for the key intermediate variables of the system. Also, the significance of reactive measures with respect to the key linking and input variables is mentioned in the discussion.

5. Results and discussion

5.1. System variables

In Table 1, the list of the 49 variables of the water management system of the Nenetzingo River watershed is presented. Each one of these variables was denominated with a representative name.

5.2. Structure of the system

Fig. 3 shows examples of the resulting matrices for analyzing the structure of the system. In the three cases that are presented in Fig. 3, the numbers in the first row and the first column represent the numbers of the variables under analysis. In Fig. 3a, a matrix of indirect influence (MDI) is represented; the values indicate the presence or absence of a relationship between the variable pair (number one or zero, respectively). Fig. 3b shows the result of elevating the combined MDI to the fifth power for generating the matrix of indirect influence (MII). Fig. 3c exposes the result of standardize the MII (each cell is divided by the higher value in the matrix). Hence its name of MIIE. Finally, in the matrix of total influence (MTI), the type of relationship between variables can be analyzed, whether direct (values zero to one), indirect (values between zero and one) or both (values greater than one), in which the value of the cell indicates the magnitude of the relationship (Fig. 3d).

As result of the use of GVF, and considering the sum of total influence, the class that represented the range for low influence grouped values between 2.975 and 18.098; The class for middle-clustered variables included data with values greater than 18.098 and up to 38.537; while the class for greater influence was grouped in values greater than 38.537 and up to 67.103. As for the sum of total dependence, the low dependence class was delimited between 3.4 and 22.881; The class for the middle-clustered variables included values above 22.881 and up to 42.502; And, finally, the class of the most dependent variables corresponded to values greater than 42.502 and up to 66.182.

With respect to the classification of the variables for delineating the structure of the system, in Fig. 4 the distribution of the MTI is shown, based on the *e*-MICMAC proposal and the categories of Godet (1994, 2000 and 2009) and Godet and Durance (2011). The variables located in the upper left quadrant are denominated as input variables (high influence and low dependence). The variables of the upper right quadrant are considered intermediate variables (high influence and dependence). Those variables located in the lower right quadrant are denominated resultant variables (little or null influence and high dependence). The variables of the lower left quadrant (zone shaded in red) were excluded (minimum or null influence and dependence). Lastly, variables that expressed mid-influence or mid-dependence may also be highlighted, complicating their inclusion in the previous categories. Thus, these were the variables denominated as middle-clustered variables (zone shaded in blue in Fig. 4).

Th structure of the system expressed the type of relationship that one variable has on the rest. In Table 1, the list of the variables categorized as input, linking and resultant variables are presented (Fig. 4).

In the case of the water management system of the Nenetzingo River watershed, the input variables influence the other variables of the system, yet few or no variables influence them. Thus, these variables may be considered impulse variables, impacting the dynamics of the system and its behavior and influencing additional components of the system as well as the system as a whole. Additionally, the condition of these input variables is more related to external factors than the system under analysis.

The intermediate variables influence the behavior of other variables but are also considerably influenced by other variables in the system (especially by the input variables). The conditions of these variables are unstable since their behavior can be directly or indirectly influenced by distinct variables or through feedback cycles. Therefore, changes to these variables result in a cascading effect on the other variables that they influence, either directly or indirectly.

As mentioned, the intermediate variables exercise influence over other variables, mainly the resultant variables. These latter variables are dependent on the behavior of the other variables (input and intermediate variables) yet are not largely influential in the behavior of other variables. Accordingly, the conditions of the resultant variables are related with internal factors of the system under analysis.

Table 1
Variables of the water management system of the Nenetzingo River watershed.

NAMES OF VARIABLES
Housing with water connection
Purchase of bottled water
Personal hygiene conditions
Access to sewage services
Access to sanitary services
Hygiene conditions in housing
Waterborne diseases
Vulnerability to health risks
Health risks
Family income from productive activities (agricultural and/or commercial) in the basin
Agricultural productivity
Access to irrigation water
Extension and condition of natural vegetation (natural forest and rain forest)
Rainfall
Natural water availability
Water quality
Pests
Quantity and status of wild fauna
Deforestation
Non-authorized water taps from the channel importing water from another basin
Non-authorized uses of water from the channel importing water from another basin
Volume of water consumption
Dumping of wastewater without adequate treatment to bodies of water
Low density housing
Use of agrochemicals
Volume of waste in septic tanks
Waste of agrochemical containers
Availability of resources for collaborating with the municipality
Cost of water and sanitation services
Landslides affecting channels for water transport
Need to search for outside work due to lack of autosufficiency/agricultural productivity
Protection of natural areas
Open defecation
Opposition to cost of sanitation services
Use of non-drinking water in housing from the channel importing water from another basin
Use of run-off water in housing and/or crops
Use of spring water in homes
Water hauling for use in homes
Drilled wells
Conflicts between water users
Distribution of water to housing and/or irrigation uses
Management of water and/or sewage services
Need to construct or optimize functional hydraulic infrastructure for providing water, sewage and wastewater treatment services
Use of septic tanks in housing
Use of latrines in housing
Promotion of sustainable water management culture
Reforestation
Community brigades for forest and rain forest conservation
Water reuse

Following the numbering in Table 1 and Fig. 1, the uncharacterized variables are numbered as 4, 5, 10, 12, 13, 17, 20, 21, 23, 25, 27, 32, 33, 35, 36, 44, 45, 47 and 48. These variables could not be clearly defined as either influencing or dependent and, hence, are not included in any of the previous classifications.

Finally, the excluded variables were numbered as 18, 26 and 31 (Table 1 and Fig. 4). These variables do not exercise considerable influence over the other components of the system, nor are they largely dependent on other variables. Thus, any modification to the conditions of these variables will not have a significant effect on the system as a whole or vice versa.

5.3. Key variables

In Fig. 5 and Table 2, the key variables obtained from the MTI, as determined by the *e*-MICMAC method, are presented. Table 2 identified the key variables with an asterisk (*), while in Fig. 5, the key variables are located outside of the zone shaded in red or blue. In this way, the key input, linking and resultant variables of the Nenetzingo River watershed may be observed.

The key variables are those that express a greater degree of influence and/or dependence and, as a consequence, are essential for the dynamics of the system. The result was a final list of 22 key variables for representing and simplifying the water management system of the Nenetzingo River watershed (Table 2).

Of these key variables, eigth are input variables, nine intermediate variables and five resultant variables. In contrast with other proposals (Aledo et al., 2008; Ambrosio-Albalá et al., 2011; Arya and Abbasi, 2001; Delgado-Martínez and Pantoja-Timarán, 2015; Delgado-Serrano et al., 2015; Estuardo-Cevallos et al., 2015), the current research study did not focus on selecting key variables located in a single, specific quadrant of the influence-dependence graph (Fig. 5). The main reason for this stance was to avoid returning to a fragmented perspective of the system in which planning is carried out without considering the dynamics of additional variables that may be highly influential or modify the planned results. For example, if the important variables of the different sectors of influence-dependence classification graph (Fig. 5) are not considered, their contribution to the possible failure of planning efforts would not be evident, and, likewise, they would then be disregarded in the design and planning of corrective measures.

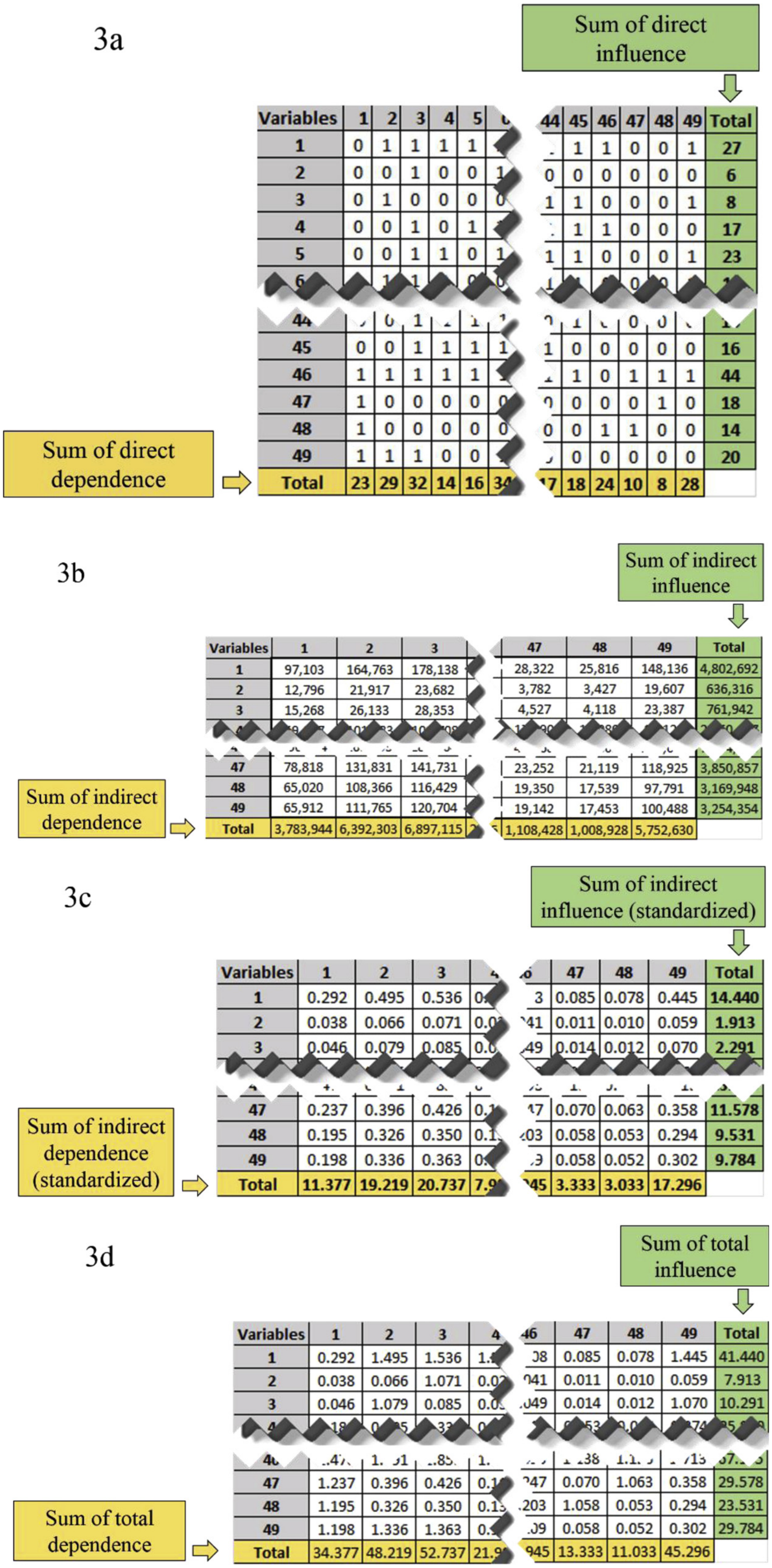
Through the identification of key variables, the complexity of the water management system of the Nenetzingo River watershed was reduced, yet the structure of the system was conserved, enabling an analysis of its dynamics from the perspective of strategic and tactical planning, which is further discussed at following.

5.4. Systemic perspective for guiding IWRM strategies and tactics

In general terms, strategic planning focuses on the measures that should be carried out, while tactical planning refers to the strategic planning stage for the implementation of the measures that should be performed or implemented, having priority the short term to try of modify the system status in a positive way. Tactical planning aims to implement strategies by means of specific and short term interventions.

In this study, the 22 key variables of the water management model of the Nenetzingo River watershed were determined. Strategic measures for ensuring IWRM in this basin should attend to these variables. From a tactical perspective, the expected results and actions with respect to these variables will vary, as explained in further detail at following.

Considering that the end goal of IWRM is to improve the living conditions of the local population through sustainable water management, in the Nenetzingo River watershed, the status of the key resultant variables (strategic) allows for an evaluation of the living conditions, as related to water usage. When unfavorable scenarios are evidently expressed by these variables, reactive actions should be undertaken to reduce negative effects. If undertaken actions produce results in the short term (months to years), then these actions are likely attending to the consequences of water-related problems and not the causes. Under this scenario, water-related problems are likely to repeat if more



3a

Sum of direct influence

Sum of direct dependence

Variables	1	2	3	4	5	45	46	47	48	49	Total
1	0	1	1	1	1	1	1	0	0	1	27
2	0	0	1	0	0	0	0	0	0	0	6
3	0	1	0	0	0	1	0	0	0	1	8
4	0	0	1	0	1	1	1	0	0	0	17
5	0	0	1	1	0	1	0	0	0	1	23
45	0	0	1	1	1	0	0	0	0	0	16
46	1	1	1	1	1	1	0	1	1	1	44
47	1	0	0	0	0	0	0	0	1	0	18
48	1	0	0	0	0	0	1	1	0	0	14
49	1	1	1	0	0	0	0	0	0	0	20
Total	23	29	32	14	16	18	24	10	8	28	

3b

Sum of indirect influence

Sum of indirect dependence

Variables	1	2	3	47	48	49	Total
1	97,103	164,763	178,138	28,322	25,816	148,136	4,802,692
2	12,796	21,917	23,682	3,782	3,427	19,607	636,316
3	15,268	26,133	28,353	4,527	4,118	23,387	761,942
47	78,818	131,831	141,731	23,252	21,119	118,925	3,850,857
48	65,020	108,366	116,429	19,350	17,539	97,791	3,169,948
49	65,912	111,765	120,704	19,142	17,453	100,488	3,254,354
Total	3,783,944	6,392,303	6,897,115	1,108,428	1,008,928	5,752,630	

3c

Sum of indirect influence (standardized)

Sum of indirect dependence (standardized)

Variables	1	2	3	47	48	49	Total
1	0.292	0.495	0.536	0.085	0.078	0.445	14.440
2	0.038	0.066	0.071	0.011	0.010	0.059	1.913
3	0.046	0.079	0.085	0.014	0.012	0.070	2.291
47	0.237	0.396	0.426	0.070	0.063	0.358	11.578
48	0.195	0.326	0.350	0.058	0.053	0.294	9.531
49	0.198	0.336	0.363	0.058	0.052	0.302	9.784
Total	11.377	19.219	20.737	3.333	3.033	17.296	

3d

Sum of total influence

Sum of total dependence

Variables	1	2	3	47	48	49	Total
1	0.292	1.495	1.536	0.085	0.078	1.445	41.440
2	0.038	0.066	1.071	0.011	0.010	0.059	7.913
3	0.046	1.079	0.085	0.014	0.012	1.070	10.291
47	1.237	0.396	0.426	0.070	1.063	0.358	29.578
48	1.195	0.326	0.350	1.058	0.053	0.294	23.531
49	1.198	1.336	1.363	0.058	0.052	0.302	29.784
Total	34.377	48.219	52.737	13.333	11.033	45.296	

Fig. 3. Example of values contained in the matrices of direct influence (MDI) (3a), indirect influence (MII) (3b), MII standardized (MIIE) (3c) and total influence (MTI) (3d) of the water management system of the Nenetzingo River watershed.

preventative measures are not taken.

A second possibility is that tactical planning would seek to implement preventative measures with respect to the key variables (strategic) in order to avoid negative conditions that would contribute to water-related problems. In this sense, there are two strategic focuses. The first focus would concentrate on variables influenced by the internal

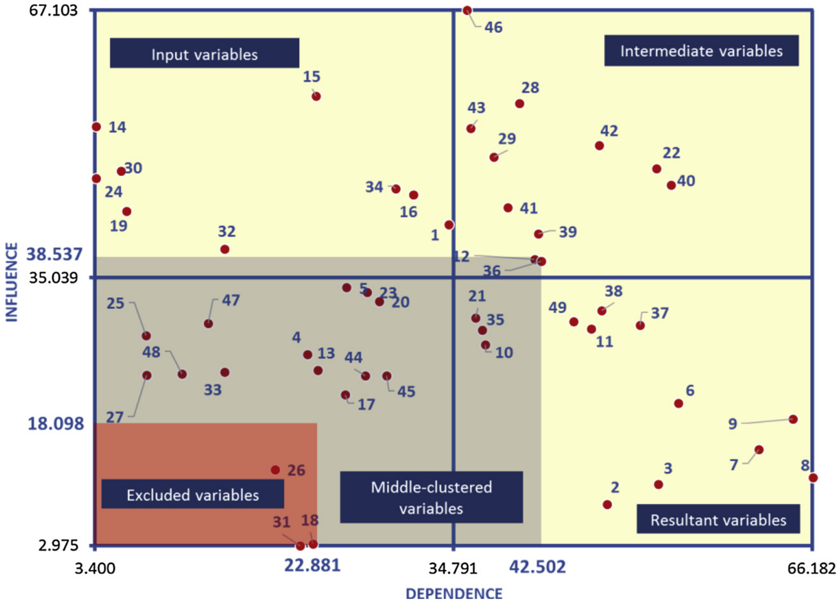


Fig. 4. Classification of the influence-dependence relationship of the variables of the water management system of the Nenetzingo River watershed of the MTI.

dynamics of the system, while the second focus would center on the variables that are influenced by the external dynamics of the system.

The first focus deals with the causes contained within the system itself, or those issues related to the key intermediate variables that are influenced by the internal dynamics of the system. In this case, tactical planning should be informed by key intermediate variables in order to generate preventative or reactive actions. Preventative actions should ensure that the conditions represented by the variables are maintained within parameters considered appropriate and that these would not generate conflict with other variables within the system. Reactive actions should be implemented if preventative actions are not effective or unable to be carried out due to extraordinary circumstances. As previously mentioned, the intermediate variables are the most unstable variables of the system, for which they should be constantly monitored. As a final note, preventative actions should necessarily involve the key input variables.

The second focus addresses the causes that are exterior to the system. These causes relate to the key input variables of the system that are more influenced by external dynamics yet also largely influence the system under study. In this case, tactical planning can be both preventative and reactive. However, due to the conditions of these variables, establishing preventative tactical actions could be complicated as a result of their dependence on aspects exterior to the system that may not be easily controlled. While alternative tactics may be formulated to address related challenges, the results will only be observable in the long term (decades). In the case of reactive actions, these should fundamentally provide short-term solutions since, to the contrary, negative consequences may be transferred to other components of the system.

Under this analytical framework, a series of sustainable solutions may be devised according to a systemic perspective, whereby a system and its components are considered during the elaboration of solutions for achieving IWRM. This approach is more favorable than the traditionally fragmented vision that often governs the management of water and related resources and that continues to prevail in Mexico.

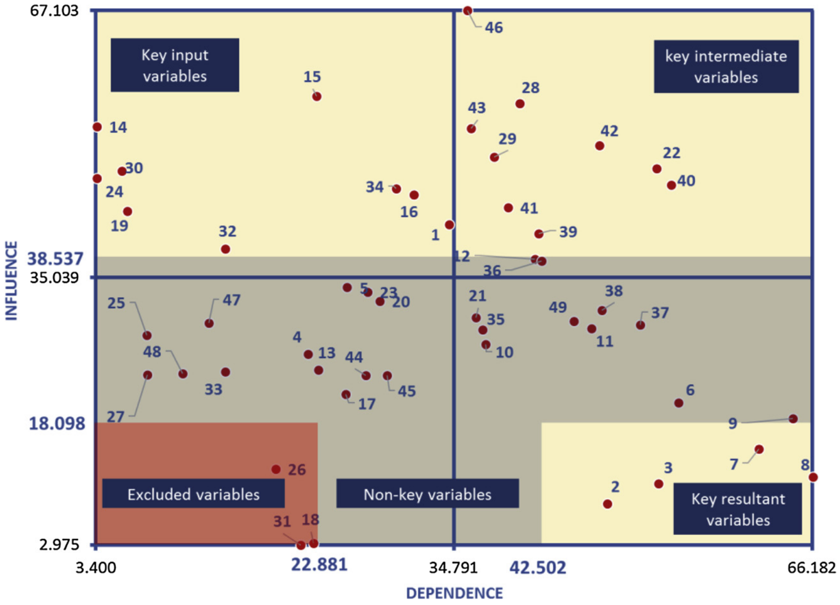


Fig. 5. Identification of the key variables of the water management system of the Nenetzingo River based on the MTI.

Table 2
Classification of the MTI variables for understanding the structure of the water management system of the Nenetzingo River watershed.

Number	Name	Classification
1	Housing with water connection	Input*
14	Rainfall	Input*
15	Natural water availability	Input*
16	Water quality	Input*
19	Deforestation	Input*
24	Low density housing	Input*
30	Landslides affecting channels for water transport	Input*
34	Opposition to cost of sanitation services	Input*
22	Volume of water consumption	Intermediate*
28	Availability of resources for collaborating with the municipality	Intermediate *
29	Cost of water and sanitation services	Intermediate *
39	Drilled wells	Intermediate *
40	Conflicts between water users	Intermediate *
41	Distribution of water to housing and/or irrigation uses	Intermediate *
42	Management of water and/or sewage services	Intermediate *
43	Need to construct or optimize functional hydraulic infrastructure for providing water, sewage and wastewater treatment services	Intermediate *
46	Promotion of sustainable water management culture	Intermediate *
2	Purchase of bottled water	Resultant*
3	Personal hygiene conditions	Resultant *
6	Hygiene conditions of housing	Resultant
7	Waterborne diseases	Resultant *
8	Vulnerability to health risks	Resultant *
9	Health risks	Resultant *
11	Agricultural productivity	Resultant
37	Use of spring water in homes	Resultant
38	Water hauling for use in homes	Resultant
49	Water reuse	Resultant

* Key variable.

6. Conclusions

Integrated water resources management (IWRM) is a framework for sustainable water management that employs a systemic perspective. Its principles may be used to analyze the management of a watershed and subsequently guide integrated management strategies and tactics. Meanwhile, structural systems analysis has the goal of identifying the relationships that exist between the components of a system in order to represent its structure and to identify its key components. These combined frameworks were successfully used to determine the key variables that should guide the water management system of the Nenetzingo River watershed.

A modified MICMAC method, the *e*-MICMAC, was outlined in this study, following the proposal of the original method but including several additional steps. For example, the elaboration of a matrix of total influence (MTI) characterized the degree to which the identified variables of the studied system held direct or indirect influence over the rest of the variables and vice versa (this step of the analysis is not specified in the original MICMAC method). Thus, this matrix enabled a better understanding of the influence that a specific variable has over another variable or the system itself, whether direct, inverse or both. At the same time, the goodness of variance fit (GVF) test was able to successfully identify the key variables as well as the variables that could not be categorized. This applied method constitutes a significant contribution to this area of research, as the original MICMAC proposal does not enable the combined influences of the variables to be assessed.

The structural analysis enabled the structure of the water management system of the Nenetzingo River watershed to be determined according to the variables that constitute the system. Furthermore, the relationships of influence and dependence between the variables of the system were identified, and these variables were then reduced in order to simplify the analysis and to focus on the key variables. The key variables outline strategic points of action that may be taken to achieve IWRM in the Nenetzingo River watershed and can be used to inform future planning tactics. In applying tactics that would improve the water management system and ensure IWRM, the living conditions of the local population would also be improved, thus fulfilling the end objective of this type of research.

The orientation of the key variables can inform strategic planning in the Nenetzingo River watershed. In particular, the key resultant variables (Purchase of bottled water, personal hygiene conditions, waterborne diseases, vulnerability to health risks and health risks) can serve as indicators of the overall functioning of the system. Moreover, the conditions of these variables could indicate the need for reactive or preventative actions that would mitigate or prevent water-related problems. The internal dynamics of the system may also be evaluated via an assessment of the intermediate variables (volume of water consumption, availability of resources for collaborating with the municipality, cost of water and sanitation services, drilled wells, conflicts between water users, distribution of water to housing and/or irrigation uses, management of water and/or sewage services, need to construct or optimize functional hydraulic infrastructure for providing water, sewage and wastewater treatment services, promotion of sustainable water management culture), and related preventative measures with respect to these variables would impede negative effects from being transferred to the resultant variables. Likewise, the external influences that the system experiences may be evaluated by considering the status of the input variables (housing with water connection, rainfall, natural water availability, water quality, deforestation, low density housing and landslides affecting channels for water transport, opposition to cost of sanitation services). Planning measures should implement schemes to monitor the behavior of these input variables and act accordingly to prevent negative conditions that could have repercussions on the rest of the system.

Strategic and tactical planning should encompass all the interconnected variables of a system, as a change to one variable may directly or indirectly impact other variables or the system as a whole. As the key variables are the most influential, interventions related to these variables will have repercussions in the system as a whole. On the other hand, the results of interventions with respect to dependent variables are more uncertain; it remains to be seen whether such interventions would be favorable or not. The monitoring of intermediate variables could help to explain how interventions with respect to the input variables translate to effects on the resultant variables. Finally, additional variables (above all, the uncategorized variables) should not be completely disregarded since a continuous monitoring of these variables could confirm or deny their relevance for planning interventions to the system.

The results presented in this study support the use of a systemic perspective for guiding water management and the implementation of IWRM. To more fully implement IWRM principles in the Nenetzingo River watershed, the following steps would be to identify the stakeholders that intercede in the key variables identified herein and to carry out further analysis of the context surrounding water governance in the watershed. Both of these steps are fundamental to effectuating actions in favor of IWRM in the Nenetzingo River watershed.

In order of to strengthen water management planning in the Nenetzingo watershed, the next steps in research are related with the definition of a scorecard to know the status each key variable and the whole system. With this information, concrete goals of tactic planning can be defined. At the same time, is possible to express a set of programs, projects, actions and stakeholders responsible for the plan.

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