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A multi-criteria decision making approach to balance water supply-demand strategies in water supply systems

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Abstract

Paper aims: this paper proposes a model to aid a group of decision makers to establish a portfolio of feasible actions (alternatives) that are able to balance water supply-demand strategies. **Originality:** Long periods of water shortages cause problems in semi-arid region of northeast Brazil, which affects different sectors such as food, public health, among others. This problem situation is intensified by population growth. Therefore, this type of decision making is complex, and it needs to be solving by a structured model. **Research method:** The model is based on a problem structuring method (PSM) and a multi-criteria decision making (MCDM) method. **Main findings:** Due to society and government influences, the proposed model showed appropriate to conduct a robust and well-structured decision making. **Implications for theory and practice:** The main contributions were the study in regions suffering from drought and water scarcity, as well as the combination of PSM and MCDM methods to aid in this problem.

Keywords

Group decision making. Water Supply Systems Plan. Strategic Options Development and Analysis (SODA). PROMETHEE V Method.

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1. Introduction

Since climate change cannot be controlled, water resources must to be managed in order to adapt the relationship between water supply and water demand to these changes (Poustie et al., 2015). In this sense, water management related just on operational routines, i.e., actions for water catchment and distribution without worrying about water availability in future, has become unacceptable (Wang et al., 2014). Thus, there are two generic strategies to water scarcity: (1) develop new sources of supply, and (2) demand management (Araral & Wang, 2013; Omar, 2013).

Demand management refers to solutions to reduce the quantity of water needed for a specific activity. This strategy seeks the efficient of water use by users (i.e. society or economic sectors), reducing and reusing water resources where possible (Brooks, 2006). In this sense, two mechanisms for regulating demand for water are most common: price and non-price mechanisms. The first occurs often through increasing block tariff; and the last includes public education, community mobilization, supply restrictions, and use of technical and engineering solutions (Araral & Wang, 2013). On the other hand, supply management aims, mainly, to increase the water availability. For this, some action should be taken to improve the water supply system, such as: modernization of equipment, expansion of the structure for both water catchment and water distribution, changes in operational and routine procedures (Wang et al., 2014).

Thus, water resources problems are complex because the Water Company need meet the rising water demand while controlling water resources levels in reservoirs in order to maintain a sufficient capacity to sustain the water supply in the future. In this way, decision making problem is about water supply-demand strategies (Wang et al., 2014), and planning appropriate portfolio of these strategies requires a wide array of options to be considered (Matrosov et al., 2013b).

In addition, issues related to water supply systems, in general, involve different actors from all levels of government and civil society organizations. Due to this, often the decision making procedure is influenced by these external pressures (Segrave et al., 2014). Moreover, in developing countries, there is a continued demand for expanding urban water infrastructure (Poustie et al., 2015). However, water distribution service has limited financial resources for its expansion and modernization (Almeida-Filho et al., 2017). Besides these issues, some regions suffer shortages of water, as for example, the mesoregion of state of Pernambuco, also called by "Agreste", located in semi-arid region of northeast Brazil.

Therefore, this paper aims to develop a multi-criteria decision making (MCDM) model to define a portfolio of alternatives to balance water supply-demand strategies. This model was applied on a water shortage problem in semi-arid region of northeast Brazil. For it, firstly, all those involved in decision making procedure should understand the problem. Thus, a problem structuring method (PSM), called by Strategic Options Development and Analysis (SODA), was used. After that, MCDM method, called by PROMETHEE V, was applied to define a set of better actions (or portfolio), that respects the constraints from Water Company.

This paper is organized as follows: Section 2 presents a literature review. In section 3, materials and methods are defined. A case study is presented in Section 4. Finally, the concluding remarks are made.

2. Literature review

In many countries, renewable water supplies are limited while demand for water is growing rapidly. This scenario is aggravated by climate changes (Hellegers et al., 2013). Thus, intensive water management measures are needed to minimize future demand–supply gaps (Ouda, 2014). In this sense, many works on water balance studied different approach to design of the effectiveness of water management policies. In general, they addressed multiple climate scenarios to test the sensitivity of water availability to changes in streamflow, precipitation and temperature, for example. The main idea is to analyse the relationship between the water supply, and its demand for a period of time. The main studies were conducted in: Dhaka city, Bangladesh (Arfanuzzaman, & Atiq Rahman, 2017); Addis Ababa, Ethiopia (Arsiso et al., 2017); Mediterranean basin (Boithias et al., 2014); Dongjiang Lake basin, China (Jie et al., 2015); Abeokuta and Environs, Southwestern Nigeria (Idowu et al., 2012); Saudi Arabia (Ouda, 2014); and Heihe River Basin in northwest China (Wu et al., 2017).

With a similar idea, Quintas-Soriano et al. (2014) made a relationship between the water supply–demand and different landscape units in semi-arid ecosystems of the southeast Iberian Peninsula. Other authors relate the water price with the decrease in its consumption as an alternative for water conservation, as were conducted in: Gold Coast, Australia (Sahin et al., 2017); Blue Mountains Australia (Haque et al., 2015); and Iran, Morocco and Saudi Arabia (Hellegers et al., 2013).

Note that all of these works were done in developing countries and/or countries that showed climatic problems. According to Azarnivand & Chitsaz (2015), "most of the arid and semi-arid regions are located in the developing countries, while the availability of water in adequate quantity and quality is an essential condition to approach sustainable development". These observations confirm the relevance of studies on water management in places such as semi-arid region of northeast Brazil. More specifically, in order to make a balance between water supply-demand strategies, Omar (2013) have studied the definition of a portfolio of actions, considering different future scenarios, in Fayoum, Egypt. However, this work did not consider multiple-criteria evaluation, but only the amount of water consumed. Thus, given the importance of the water resource and the variety of criteria involved in this decision making process, suitable decision making tool, as multi-criteria decision making (MCDM), is necessary to ensure the success and effectiveness of water supply systems (Garfí & Ferrer-Martí, 2011).

In this point of view, there are some studies that used MCDM methods or group decision-making on water resources management. Some of these studies, as well as the criteria considered, can be visualized in Table 1.

Although these works did not solve the problem reported in this study (Table 1), they demonstrate the applicability of MCDM methods to solve water management problems. The main criteria used were grouped into technical, social, environmental and economic.

On the other hand, regarding the problem of selecting portfolios of water supply-demand strategies, Matrosov et al. (2013a) proposed the Robust Decision Making (RDM) to solve it under uncertainty situation. They considered the same criteria used by Matrosov et al. (2013b), see Table 1, but they added resilience as

Table 1. Evaluation criteria and methods applied to water management.

Authors (year)	Main problem	Method	Criteria
Chung & Lee (2009)	Prioritization of water management	Analytic Hierarchy Process (AHP)	Five criteria: Driver, Pressure, State, Impact, and Response. Sub criteria were defined in two classes: water quantity and water quality.
Garfí & Ferrer-Martí (2011)	Water and sanitation projects evaluation	Do not use	They were classified in 4 main groups: technical (e.g. local resources use, appropriate management); social (e.g. local community participation, overcoming discrimination of conflict); economic (e.g. low cost, employment of local staff) and environmental criteria (e.g. atmospheric emissions, water pollution).
Garfí et al. (2011)	Environmental assessment of water programmes	AHP	They selected two main criteria: (1) General criteria for human development projects (technical, social, environmental and economic criteria - 11 sub criteria) and (2) Technical water supply criteria (12 sub criteria).
Fontana & Morais (2013)	Network rehabilitation	PROMETHEE V	Amount of water loss, Implementation cost, Maintenance cost, Runtime, and Reliability time.
Kim et al. (2013)	Wastewater	Fuzzy TOPSIS	Five criteria: Driver, Pressure, State, Impact, and Response. Sub criteria were defined in two classes: water quantity and water quality.
Matrosov et al. (2013b)	Water resources planning	Robust Decision Making (RDM) and Info-Gap Decision Theory (IGDT)	Reliability of water supply service, Reservoir storage susceptibility, Environmental performance, Energy consumption, and Total costs.
Scholten et al. (2014)	Network rehabilitation	Multi-attribute value model (MAVM)	Reliability, Intergenerational equity, and Cost
Azarnivand & Chitsaz (2015)	Water shortage mitigation	AHP, eDPSIR and DEMATEL	Human population growth, Weak enforcement of law and legislation, Erosion, Declining available freshwater resources, Desertification and sand and dust storms, Salinization, Operational feasibility, and Multi-objectivity.
Fontana & Morais (2015)	Network segmentation	SMARTER	Amount of economies (number), Type of economies, Water consumed, and Price tax.
Scholten et al. (2015)	Water supply infrastructure planning	Multi-attribute utility theory (MAUT)	Five fundamental objectives: Intergenerational equity, Resources and groundwater protection, Water supply, Social acceptance, and Costs.
Fontana & Morais (2016)	Water loss control	SMARTER and Integer linear programming (ILP)	Implementation cost, Efficiency, Runtime, Potential reduction in wastewater, Skilled labour to implement, and Lifetime.
Kumar et al. (2016)	Water allocation	ELECTRE-III-H	Costs, Water stress, and Environmental impact
Almeida-Filho et al. (2017)	Network maintenance	Voting procedure	System Average Interruption Frequency Index, Reliability, Availability, and Cost per cycle.
Fontana & Morais (2017)	Network segmentation	PROMETHEE GDSS	Implementation cost, Number of segments generated, Water consumed, Difficulty level in implementing and maintaining, Change in network pressure and/or water flow, Type of economies, and Infrastructure impact.
Ilaya-Ayza et al. (2017)	Water supply schedule	AHP and ILP	Pressure, Number of users, Number of supply hours, and Ease of operation of the sectors.

a criterion. However, information related on these uncertainties is not always clear to the decision makers (DM). In addition, the RDM method performs a trade-off between evaluations of actions over different criteria. This procedure does not always reflect the opinions of a group of heterogeneous DMs, generating a high level of dissatisfaction.

Moreover, this type of problem is complex, and a structured procedure to increase understanding of the problem is important. Thus, all relations are best understood by those involved in decision making process (Belton & Stewart, 2002). Some authors have been used PSMs to support the decision making in water resources problems, such as: water basins (Cakmak, et al., 2013; Suriya & Mudgal, 2013); perceptions of water users (ElSawah et al., 2013); and water resource conflicts (Medeiros et al., 2017; Urtiga & Morais, 2015). “Combining PSMs and MCDA produces a richer view of the decision situation and provides a methodology which can better handle the various phases of decision-making [...]” (Marttunen et al., 2017, p. 1).

2.1. Problems Structuring Methods (PSM)

Frequently, alternatives and criteria used in a problem analysis are not clearly defined. Problem Structuring Methods (PSMs) are useful to enable greater understanding of problems prior to define appropriate actions (Foote et al., 2007). They assist in the structuring and definition of the critical issues that constitute the problem, and understanding the relationships between these issues (Cunha & Morais, 2016). Thus, PSMs are a valued way to address real management issues (Abuabara et al., 2017).

In this context, Strategic Options Development and Analysis (SODA) is a method that aids decision making, especially in complex problems. This approach is based on the premise that subjectivity is inherent in the decision making process, i.e., different people will interpret differently the same situation (Eden, 1988). SODA uses cognitive maps to understand and record the views of the individuals involved (stakeholders) in the decision making (Eden & Ackermann, 2004). A cognitive map can be understood as a means to separate and represent constructs (ideas, information) from an stakeholder, and position them in the form of hierarchy (Eden, 1988). In this sense, cognitive maps use nodes to represent events, and arcs that connect these events and represent the causal relationship between them. A cognitive map can be generated with all stakeholders together, or it can be constructed from the aggregation of individual cognitive maps (Cunha & Morais, 2016).

2.2. Multi-Criteria Decision Making (MCDM)

The MCDM methods are useful in situations where there is a decision making that must meet multiple objectives in an integrated manner (Almeida et al., 2015). The MCDM methods can be differentiated by (1) type of problematic that they intend to solve, such as choice, sorting, ranking, description, design and portfolio (Belton & Stewart, 2002); and (2) by the rationality of the DM, in compensatory methods or non-compensatory methods (Almeida et al., 2015).

PROMETHEE methods are non-compensatory, and they construct a valued outranking relationship, where a bad evaluation of an alternative on a criterion cannot be compensated by a good evaluation on other criteria (Brans et al., 1986). Brans & Mareschal (1992) developed the PROMETHEE V method to solve portfolio problematic. More specifically, this method is divided into two phases: (1) PROMETHEE II method, and (2) Integer linear programming (ILP).

Given a general pair of alternatives (a,b), and the function $g_j(.)$ the performance of the alternatives in each criterion j, according to Brans & Mareschal (2009), in PROMETHEE II, the DM establishes a weight (w_j) for each criterion *j*, where $j=\{1,2,\ldots,k\}$, and a preference function $F_j(a,b)$ of the difference $\left[g_j(a)-g_j(b)\right]$ between the performance of the alternatives in each criterion *j*. Thus, the evaluation is made by the degree of outranking $(\pi(a,b))$ for each pair of alternatives, represented by Equation 1. The weights must be normalized, i.e., $\sum_j^k w_j = 1$.

$$\pi(a,b)=\sum_{j=1}^{k} w_j F_j(a,b) \tag{1}$$

After that, the degree of outranking relationship is explored through the negative outranking flows $\Phi^-(a)$ and positive outranking flows $\Phi^+(a)$, as follows:

- Positive: it represents the intensity preferably of an alternative '*a*' on all alternatives '*b*' in set *A*, as in Equation 2.

$$\Phi^+(a)=\sum_{b\in A}\pi(a,b) \tag{2}$$

- Negative: it represents the intensity preferably of all alternatives '*b*' on the alternative '*a*' in the set *A*, as in Equation 3.

$$\Phi^-(a)=\sum_{b\in A}\pi(b,a) \tag{3}$$

Thus, the solution is given by the net flow of alternatives by Equation 4.

$$\Phi(a)=\Phi^+(a)-\Phi^-(a) \tag{4}$$

In ILP phase, the net flow from PROMETHEE II solution is used as the objective function coefficients, as in Equations 5-7 (Brans & Mareschal, 1992; Fontana & Morais, 2013).

$$Máx\sum_{i=1}^{n}\Phi_i x_{ai} \tag{5}$$

Subject to

$$\sum_{i=1}^{n} b_{ij} x_{ai} \le B_j \qquad \forall j \tag{6}$$

$$x_{ai} = [0;1] \tag{7}$$

Where: x_{ai} represents an alternative, and $i = \{1,2,\ldots,n\}$; Φ_i is the net flow of each alternative x_{ai}; b_{ij} is the value of each alternative x_{ai} on constraint *j*, and $j = \{1,2,\ldots,m\}$; B_j is the upper limit of the constraint *j*.

This classical model of PROMETHEE V method automatically excludes alternatives that present a negative net flow. Thus, Vetschera & Almeida (2012) proposed other constraint, *c*-optimal, that solve this problem, as in Equation 8.

$$\sum_{i=1}^{n} x_{ai} = c \tag{8}$$

Where: c is a fixed number for the number of alternatives to be inserted in a portfolio.

3. Materials and methods

This section presents the steps of the proposed model to balance water supply-demand strategies, as in Figure 1.

In Figure 1, the "feedback" means that is always possible to return to previous steps in order to improve the final solution. Thus, the model is adaptable to different decision making situations. Thereby, the decision making process becomes dynamic, and new information can be inserted at any time during this process.

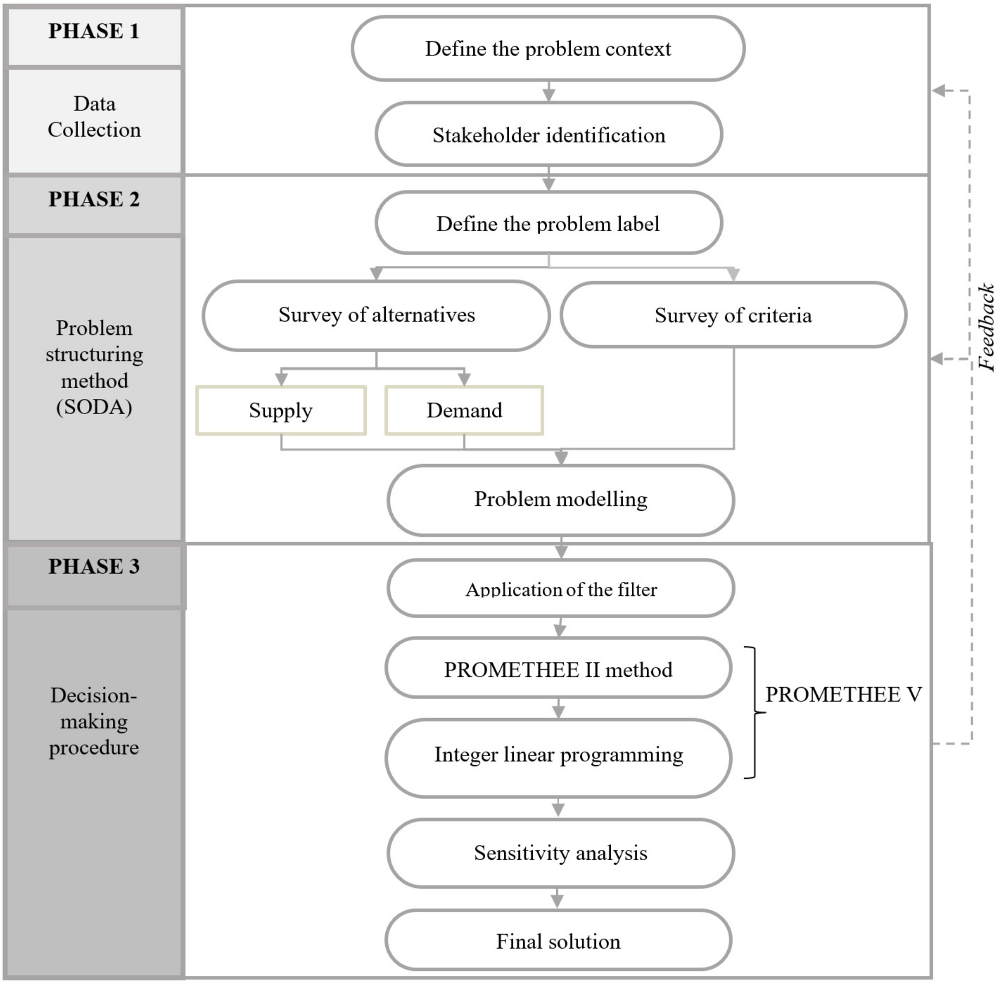

Figure 1. Model for strategic decision making on water management.

3.1. Data collection

Data collection is fundamental for a better understanding about the situation, and it serves to identify key aspects to start the problem structuring method (PSM). Thus, the steps are as follows:

(1) Define the problem context - this step aims to understand the scenario of the problem. Some relevant information is, for example: the amount of water demand, the water level in the reservoirs, the amount of water lost in the water supply system (WSS), among others;

(2) Stakeholder identification - in this step all actors directly or indirectly involved in the problem must to be identified. The responsibility of each DM need to be established. Moreover, external influences, or pressures, in the decision making process should to be known. In addition, a person responsible for conducting the process can be defined. He/she is called as facilitator or decision making analyst.

3.2. Strategic Options Development and Analysis (SODA)

SODA was chosen because it was developed to aid decision making procedure in complex problems. The facilitator will capture DMs' perceptions about the problem through workshops, following the steps bellow, based on Eden & Ackermann (2004):

(1) Define the problem label: DMs will define a label that represents the problem being treated. This problem should be established as a result from important issues raised before (Phase 1);

(2) Survey of alternatives: DMs are invited to propose suggestions on water supply-demand strategies, and the result will be a global cognitive map, containing: (1) alternatives able to increasing water supply, and (2) alternatives able to reducing water demand;

(3) Survey of criteria: DMs define a set of evaluation criteria. This set allows making the judgment between potential alternatives to solve the problem;

(4) Problem modelling: The performance of each alternative on each criterion is evaluated by the DMs and/or the Supra decision maker (SDM). Thus, the evaluation matrix is created.

3.3. Decision making procedure

In this type of problem, commonly, a bad evaluation from an alternative on a criterion cannot be compensated by a good evaluation on another criterion. In others words, this problem shows non-compensatory nature. For this reason, the PROMETHEE V method was chosen, and its application was based on Brans & Mareschal (2009), as the following steps:

(1) Filter: it aims to eliminate irrelevant alternatives on process. In general, it occurs due to budget constraints, for example. This step also allows the elimination of criteria when they are irrelevant in pairwise comparison of alternatives;

(2) PROMETHEE II: here some parameters must to be established according to DMs' preferences, such as: weights, thresholds (indifference, preference and veto), and preference function for each criterion. After that, the PROMETHEE II method executes a pairwise comparison of alternatives over each criterion in order to obtain the net flow. This method was performed in the academic edition of Visual PROMETHEE software, version 1.4.0.0;

(3) Integer linear programming (ILP): in this step the problem constraints are added, in order to define a portfolio of alternatives, which include both water supply-demand alternatives;

(4) Sensitivity analysis: this analysis aims to assess the robustness of the model;

(5) Final solution: finally, the final solution is confirmed. It must represent the DMs' preferences, and it must respect the problem constraints.

4. Case study

The proposed model was applied at Water Company (WC) localized in semi-arid region of Pernambuco state. Usually, decisions making were focused on routine management, and they were made without specific methods to support decision making procedure. This fact enables a strong political influence from government over WC presidency.

4.1. Data collection

In addition to data collected directly from Water Company, the data were collected from National Water Agency (ANA) and “Historical Series 2015” available on website of the National Sanitation Information System (SNIS). In addition to these sources, it has been studied scientific researches developed on water resources.

In the case studied, in June of 2015, two water reservoirs were responsible for supplying the region, the reservoirs of the Prata and Jucazinho. At this time, the real capacity of these reservoirs was 61.76% and 7.10%, respectively. More recently, in March 2017, the Jucazinho reservoir capacity was 0%, while the Prata reservoir capacity was 16.42%. These data prove the collapse in the water reservoir, i.e., water level is dropping drastically in this region. Table 2 shows the situation of these water reservoirs in June 2015 and March 2017.

Table 2. Situation of water reservoirs.

Reservoir	Total capacity (m³)	in Jun 2015		in March 2017	
		Volume (m³)	Water catchment (m³/d)	Volume (m³)	Water catchment (m³/d)
Prata	42,147,000.00	26,028,278.54	60,480.00	6,919,513.91	4,5792.00
Jucazinho	327,045,336.00	23,232,108.30	93,312.00	0	0
Total	369,192,336.00	49,260,386.84	153,792.00	6,919,513.91	4,5792.00

In addition to these reservoirs, the region was already supplied by the reservoirs of Tabocas, Taquara, Poço Fundo, all in the process of collapse in the water supply; and the reservoirs of Jaime Nejaim and Serra dos Cavalos which today have their water catchment prevented by environmental issues. However, due the current scenario of water shortage, theses reservoirs can be used again.

In 2015 the average water consumption per capita was approximately 94.76 litres per day, while in 2017 it decreased to 84.11 litres per day. Despite the decrease in consumption, from 14 cities supplied in 2015, only 04 cities are being supplied regularly in 2017. In other words, about 36% of the total population is not being supplied.

Therefore, an overview of the current situation faced by the WC can be elaborated. The main problem encountered in the region studied was: trend of water levels drop dramatically.

4.2. SODA

Following the SODA procedure, into a workshop, the DMs were invited to establish a set of available alternatives. In this study were considered as stakeholders all employees from Regional Business Unit Management of the Agreste Central who hold a management position, as well as the employees that participate as technical support level. Therefore, in total, there are 09 DMs in this case study.

Thus, the proposed model was presented to DMs, and, after that, a label was defined for the problem, which was: *Continuity of water supply during times of drought.* In sequence, the facilitator captured DMs' point of views on the problem, and a cognitive map was resulted, as in Figure 2.

Therefore, after carrying out refinements, the set of available alternatives able to increase water supply was:

- A_{11} – Watershed transposition: This involves construction of adductor systems to adapt the water supply systems, and it allows the water transposition between watersheds. This is a part of the San Francisco River transposition project;
- A_{12} - Integrated water mains: Implement structural works for water mains extension to integrate water mains of different WSS;

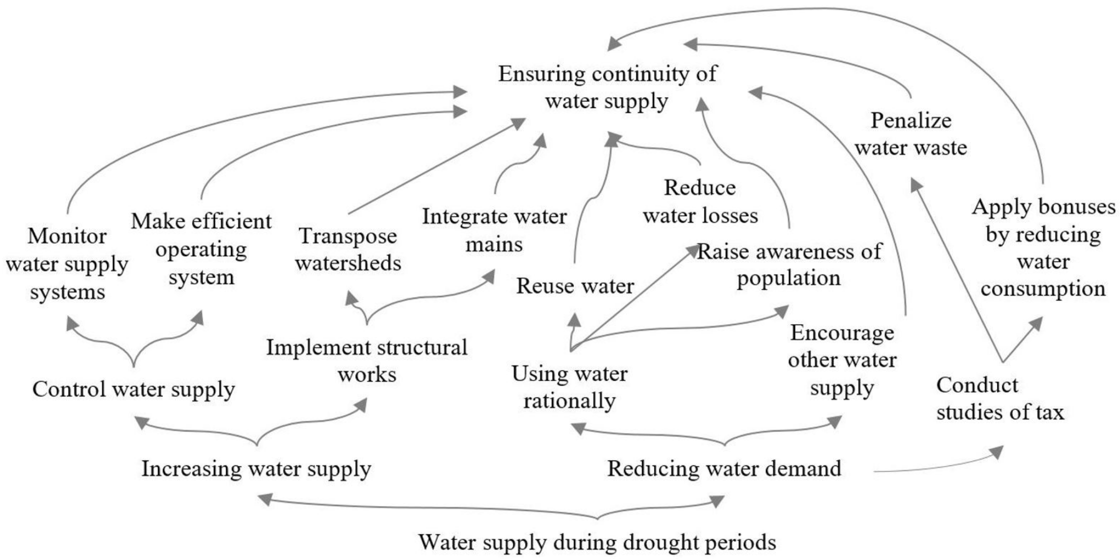

Figure 2. Global cognitive map: Supply-Demand strategies.

- A_{13} – Monitoring: Monitoring the WSS by deploying automation systems;
- A_{14} - Preparation of operation manual systems: A technical team is created to conduct the development of a manual with standard procedures to be performed in each problem.
- While, the set of available alternatives able to reduce the demand for water was:
- A_{21} - Create taxes program: Implement a program to reduction the water taxes, when the users (or consumers) reduce their water consumption in a pre-defined range;
- A_{22} - Penalize water waste: A technical team is created to monitor and applied taxes in cases of water waste from users, such as: large water leaks, water renewal of pools, washing the sidewalks, etc.;
- A_{23} - Encourage other water supply alternatives: A technical team is created to guide users in the development and use of other water supply alternatives, such that rainwater harvesting, and its use in discharges and/or gardening, for example;
- A_{24} - Public campaigns: A technical team is created to conduct population awareness campaigns about the importance of rational water use;
- A_{25} - Water loss reduction program: A technical team is created to develop and implement the water loss reduction program in water distribution system (WDS);
- A_{26} - Water reuse systems: A technical team is created to analyse and build water recycling and reuse systems during the treatment.

At Water Company, the DMs are specialists in different areas, and, usually, they have conflicting interests. Thus, each DM suggested criteria most relevant to their area of expertise. However, they entered into a consensus that the final decision making should be taken by the Regional Business Manager. In this case, he represents a SDM. Therefore, the SDM analysed the set of potential criteria suggested by DMs, and the following five criteria were defined:

- C_1 - Implementation cost: This criterion corresponds to the initial investment estimate for implemented each alternative;
- C_2 - Response time: This criterion is the estimated time for an alternative to return the expected benefits;
- C_3 - Social benefit: This criterion estimates the benefit generated to the society by the chosen alternative. This evaluation can be done through the percentage of users who are probably to benefit from the alternative.

Thus, a nominal scale was used, that is: (1) Very low (VL): less than 20%; (2) Low (L): from 20 to 40%; (3) Moderate (M): from 40 to 60%; (4) High (H): from 60 to 80%; (5) Very high (VH): over than 80%;

- C_4 - Demand reduction: This criterion estimates a percentage that is expected to reduce in the water consumed by the chosen alternative. Thus, a nominal scale was used, that is: (0) There is no reduction; (1) Very Low reduction (VL): less than 10%; (2) Low reduction (L): from 10 to 20%; (3) Moderate reduction (M): from 20 to 30%; (4) High reduction (H): from 30 to 40%; (5) Very high reduction (VH): over than 40%;
- C_5 – Viability: This criterion is related to the technical complexity for implementation of the chosen alternative. This evaluation was made according the following nominal scale: (1) Simple; (2) Little complex; (3) Moderately; (4) Complex; and (5) Very complex;
- C_6 - Water supply: This criterion refers to an estimate of the increase in water supply by the chosen alternative. The values used are an approximate average of the expected quantity.

The decision making matrix of this problem was made by the SDM, and it is presented in Table 3. For this, the estimated values of consequence were used considering similar projects already applied previously. Moreover, the SDM established the parameters required by the PROMETHEE II method. These data was obtained in June 2015.

Table 3. Decision making matrix and parameters required by the model.

Alternative	C_1 (millions - R$)	C_2 (months)	C_3 (nominal)	C_4 (percentage)	C_5 (nominal)	C_6 (m^3/ second)
A_{11}	1,350.00	24	Very high	NO	Very complex	8.0
A_{12}	750.00	36	High	NO	Very complex	4.0
A_{13}	8.00	36	Very low	NO	Little complex	0.0
A_{14}	2.00	60	Low	NO	Moderately	0.0
A_{21}	1.50	2	Moderate	Low	Little complex	0.0
A_{22}	0.30	1	High	Moderate	Complex	0.0
A_{23}	1.20	60	Very high	Low	Moderately	0.0
A_{24}	5.00	60	Low	Very low	Complex	0.0
A_{25}	100.00	120	High	NO	Moderately	0.3
A_{26}	1.00	24	Moderate	NO	Moderately	0.0
Parameters	C_1	C_2	C_3	C_4	C_5	C_6
Objective	Minimize	Minimize	Maximize	Maximize	Minimize	Maximize
Weight	0.20	0.05	0.25	0.20	0.1	0.2
Preference function	Level criterion	U-Shape criterion	Usual criterion	Usual criterion	Usual criterion	Usual criterion
Threshold	$q = 0.5$	$q = 2.0$	--	--	--	--
	$p = 1.0$	--	--	--	--	--

4.3. Decision making procedure

Importantly, in 2015 Brazil's economy entered a deceleration process, which led to cuts in the overall government budget. Thus, the SDM informed an available budget of R$ 7.2 million in current year. Thus, a filter step can be applied before the decision making step. In other words, alternative with an implementation cost above the available budget can be eliminated. In this case, the alternatives A_{11}, A_{12}, $A_{13,}$ and A_{25} exceed the available budget. However, these alternatives will not be eliminated in this first moment in order to illustrate the consequences.

Therefore, a complete pre-order is given by PROMETHEE II method, that is: $A_{23}>A_{22} >A_{21}> A_{11}> A_{25}>A_{26}> A_{12}>A_{14}> A_{24}> A_{13}$. A sensitivity analysis should be done. Thus, the weights of the criteria were changed in $\pm 10\%$, respecting the sum of all weights equals 1. The robustness of the model was confirmed because it did not change the first ones. Considering the order resulting from PROMETHEE II method, only the first three alternatives could be implemented, since alternatives A_{11} and A_{25} present a cost higher than the available budget.

However, besides the currently budget, the WC is able to request external resource, usually from the Federal Government, to finance a specific project. This is because, although the facilities of WSS are granted to Water

Company, they are public. Normally, the projects compete with others in all countries to obtain the necessary funding. In addition, the financial resources can also be obtained through other institutions, such as the World Bank. Therefore, DMs should consider submitting projects for the financing of such alternatives (A_{11} and A_{25}).

From this analysis, the Filter step will be executed, and alternatives that exceed the current budget will be eliminated. After that, the criterion C_6 was also eliminated because it becomes irrelevant in the evaluation procedure. Then, a new weight elicitation was preceded, and the weights are: $C_1 = 0.2667$, $C_2 = 0.0667$, $C_3 = 0.3333$, $C_4 = 0.2000$, $C_5 = 0.1333$. Therefore, the complete pre-order from PROMETHEE II method was: $A_{22}>A_{23}>A_{21}>A_{26}>A_{14}>A_{24}$.

Thus, an ILP was developed to select a portfolio of alternatives, as follows:

$$\text{MáxZ} = -0.5200x_{A14} + 0.2667x_{A21} + 0.5601x_{A22} + 0.4533x_{A23} - 0.7200x_{A24} - 0.0400x_{A26} \quad (10)$$

Subject to

$$2x_{A14} + 1.5x_{A21} + 0.3x_{A22} + 1.2x_{A23} + 5x_{A24} + 1x_{A26} \le 7.2 \quad (11)$$

$$x_{14} \ge 1 \quad (12)$$

$$x_{21} + x_{22} + x_{23} + x_{24} + x_{A26} \ge 1 \quad (13)$$

$$x_{A14} + x_{A21} + x_{A22} + x_{A23} + x_{A24} + x_{A26} = 5 \quad (14)$$

$$x_{A14},\ x_{A21}, x_{A22}, x_{A23}, x_{A24}, x_{A26} = [0;1] \quad (15)$$

Where: (10) is the objective function, where the coefficients are the values of net flow from PROMETHEE II method; (11) is the budget constraint on implementation; (12) and (13) ensure that there is at least one alternative to increase water supply and one alternative to reduce the water demand, respectively; (14) *c*-optimal; (15) is the value of the decision variable x_i: this value is a integer value 0 or 1, where 1 means that x_i is part of the solution, and 0 otherwise.

Therefore, the resulting portfolio of alternatives was: A_{14}, A_{21}, A_{22}, A_{23}, and A_{26}. The alternatives selected represent a total cost of R$6 million. Thus, it would be allocated approximately 83% of available budget for the implementation of these alternatives. The *c*-optimal constraint, Equation 14, allows the choice of two alternatives (A_{14} and A_{26}) that would not be considered by the PROMETHE V classic method due to their negative net flow.

In addition, another sensitivity analysis step should be done to confirm the robustness of the model. For that, the weights were changed in ± 5%, respecting the sum of all weights equals 1. Thus, the complete pre-order established by the PROMETHEE II method suffers only changes on the top three in rank (A_{22}, A_{23}, and A_{21}) when the criteria lost 5% in their weight. However, the portfolio of alternatives given by PROMETHEE V method has not changed, which proves the robustness of this model.

5. Concluding remarks

The proposed model was able to make the balance water supply-demand strategies through selecting alternatives for both supply and demand. Due to society and government influences, this model provides means to support decision making in Water Company, and, thus, it can aid to justify the chosen alternatives. This can be adapted and applied in others Water Companies, mainly in developing countries.

An important contribution of this work was the clear consideration of alternatives to reduce demand and to increase supply. This thought did not exist in the company studied; before procedures and initiatives were not clear, mainly related to the reduction of water demand.

The results show that in scenarios of great budgetary constraint it is relevant to evaluate all the alternatives in order to avoid the early elimination of these alternatives. For example in 2015, there was no water loss control, and DMs did not think about this possibility (A_{25}). However, in 2016, the WC started a project with external support to control water loss in its WDS.

Moreover, during the execution of this research was observed an interest from stakeholders about this type of study. Participants said that they did not participate in a similar process before. In addition, they were addressed during a critical time in which the drought problem was already accelerating. Thus, DMs were suffering heated discussions and exhaustion that affecting everyone. This fact may have influenced the results of this work. However, participants emphasized the importance of this model, and their interest in reapplying in other situations. Such behaviour reinforces the need for research to support this type of decision making. However, there are cultural barriers in the organization environment that make it difficult to implement the proposed model.

Therefore, this paper hopes to serve to demonstrate that the conduction of decision making processes based on "trial and error" should be replaced by more robust, and well-structured decision making, especially because WC deal with the difficult task of supplying the population in times of drought.

Moreover, according to a literature review, the evaluation criteria most used in water management decision making processes are grouped into four main categories: technical, social, environmental and economic. The decision makers consulted were consistent in this regard. The environmental criterion was only criterion little explored. Although this criterion is inherent to the process, decision-makers did not present this criterion as a priority. Maybe aspects related to the country's environmental laws may justify such conduct. However, further study on this criterion should be made as future work. Finally, one suggestion for future work is to study this problem when there is no consensus in the opinions of DMs.

References

Abuabara, L., Paucar-Caceres, A., Belderrain, M. C. N., & Burrowes-Cromwell, T. (2017). A systemic framework based on Soft OR approaches to support teamwork strategy: an aviation manufacturer Brazilian company case. *Journal of the Operational Research Society*, 1-15. http://dx.doi.org/10.1057/s41274-017-0204-9.

Almeida, A. T., Cavalcante, C. A. V., Alencar, M. H., Ferreira, R. J. P., Almeida-Filho, A. T., & Garcez, T. V. (2015). *Multicriteria and multiobjective models for risk, reliability and maintenance decision analysis. International Series in Operations Research and Management Science*. New York: Springer. https://doi.org/10.1007/978-3-319-17969-8.

Almeida-Filho, A. T., Monte, M. B. S., & Morais, D. C. (2017). A Voting approach applied to preventive maintenance management of a water supply system. *Group Decision and Negotiation*, *26*(3), 523-546. http://dx.doi.org/10.1007/s10726-016-9512-8.

Araral, E., & Wang, Y. (2013). Water demand management: review of literature and comparison in South-East Asia. *International Journal of Water Resources Development*, *29*(3), 434-450. http://dx.doi.org/10.1080/07900627.2013.826413.

Arfanuzzaman, M., & Atiq Rahman, A. (2017). Sustainable water demand management in the face of rapid urbanization and ground water depletion for social–ecological resilience building. *Global Ecology and Conservation*, *10*, 9-22. http://dx.doi.org/10.1016/j.gecco.2017.01.005.

Arsiso, B. K., Tsidu, G. M., Stoffberg, G. H., & Tadesse, T. (2017). Climate change and population growth impacts on surface water supply and demand of Addis Ababa, Ethiopia. *Climate Risk Management*, *18*, 21-33. http://dx.doi.org/10.1016/j.crm.2017.08.004.

Azarnivand, A., & Chitsaz, N. (2015). Adaptive policy responses to water shortage mitigation in the arid regions—a systematic approach based on eDPSIR, DEMATEL, and MCDA. *Environmental Monitoring and Assessment*, *187*(2), 1-15. PMID: 25626561. http://dx.doi.org/10.1007/s10661-014-4225-4.

Belton, V., & Stewart, T. (2002). *Multiple criteria decision analysis: an integrate approach: an integrated approach*. Norwell: Kluwer Academic Publishers. http://dx.doi.org/10.1007/978-1-4615-1495-4.

Boithias, L., Acuna, V., Vergonos, L., Ziv, G., Marce, R., & Sabater, S. (2014). Assessment of the water supply: demand ratios in a Mediterranean basin under different global change scenarios and mitigation alternatives. *The Science of the Total Environment*, *470–471*, 567-577. PMid:24176705. http://dx.doi.org/10.1016/j.scitotenv.2013.10.003.

Brans, J. P., & Mareschal, B. (1992). PROMETHEE V: MCDM problems with segmentation constraints. *INFOR*, *30*(2), 85-86. http://dx.doi.org/10.1080/03155986.1992.11732186.

Brans, J. P., & Mareschal, B. (2009). PROMETHEE methods. In J. R. Figueira, S. Greco & M. Ehrgott (Eds.), *Multiple criteria decision analysis: state of the art surveys* (pp. 163-195). New York: Springer-Verlag. Retrieved in 2017 July 24, from http://www.springer.com/it/book/9780387230672

Brans, J. P., Vincke, P. H., & Mareschal, B. (1986). How to select and how to rank projects: the PROMETHEE method. *European Journal of Operational Research*, *24*(2), 228-238. http://dx.doi.org/10.1016/0377-2217(86)90044-5.

Brooks, D. B. (2006). An operational definition of water demand management. *International Journal of Water Resources Development*, *22*(4), 521-528. http://dx.doi.org/10.1080/07900620600779699.

Cakmak, E. H., Dudu, H., Eruygur, O., Ger, M., Onurlu, S., & Tonguç, Ö. (2013). Participatory fuzzy cognitive mapping analysis to evaluate the future of water in seyhan basin. *Journal of Water and Climate Change*, *4*(2), 131-145. http://dx.doi.org/10.2166/wcc.2013.029.

Chung, E. S., & Lee, K. S. (2009). Prioritization of water management for sustain- ability using hydrologic simulation model and multicriteria decision making techniques. *Journal of Environmental Management*, *90*(3), 1502-1511. https://doi.org/10.1016/j.jenvman.2008.10.008.

Cunha, A. A. R., & Morais, D. C. (2016). Analysing the use of cognitive maps in an experiment on a group decision process. *The Journal of the Operational Research Society*, *67*(12), 1459-1468. http://dx.doi.org/10.1057/jors.2016.19.

Eden, C. (1988). Cognitive mapping: a review. *European Journal of Operational Research*, *36*(1), 1-13. http://dx.doi.org/10.1016/0377-2217(88)90002-1.

Eden, C., & Ackermann, F. (2004). Cognitive mapping expert views for policy analysis in the public sector. *European Journal of Operational Research*, *152*(3), 615-630. http://dx.doi.org/10.1016/S0377-2217(03)00061-4.

ElSawah, S., Mclucas, A., & Mazanov, J. (2013). Using a cognitive mapping approach to frame the perceptions of water users about managing water resources: a case study in the Australian capital territory. *Water Resources Management*, *27*(9), 3441-3456. http://dx.doi.org/10.1007/s11269-013-0357-5.

Fontana, M. E., & Morais, D. C. (2013). Using Promethee V to select alternatives so as to rehabilitate water supply network with detected leaks. *Water Resources Management*, *27*(11), 4021-4037. http://dx.doi.org/10.1007/s11269-013-0393-1.

Fontana, M. E., & Morais, D. C. (2015). Segmentation model for water distribution networks based on the characteristics of consumer units. *Production*, *25*(1), 143-156. http://dx.doi.org/10.1590/S0103-65132013005000071.

Fontana, M. E., & Morais, D. C. (2016). Decision model to control water losses in distribution networks. *Production*, *26*(4), 688-697. http://dx.doi.org/10.1590/0103-6513.201815.

Fontana, M. E., & Morais, D. C. (2017). Water distribution network segmentation based on group multi-criteria decision approach. *Production*, *27*(0), e20162083. http://dx.doi.org/10.1590/0103-6513.208316.

Foote, J. L., Gregor, J. E., Hepil, M. C., Baker, V. E., Houston, D. J., & Midgley, G. (2007). Systemic problem structuring applied to community involvement in water conservation. *The Journal of the Operational Research Society*, *58*(5), 645-654. http://dx.doi.org/10.1057/palgrave.jors.2602248.

Garfí, M., & Ferrer-Martí, L. (2011). Decision-making criteria and indicators for water and sanitation projects in developing countries. *Water Science and Technology*, *64*(1), 83-101. PMid:22053462. http://dx.doi.org/10.2166/wst.2011.543.

Garfí, M., Ferrer-Martí, L., Bonoli, A., & Tondelli, S. (2011). Multi-criteria analysis for improving strategic environmental assessment of water programmes. A case study in semi-arid region of Brazil. *Journal of Environmental Management*, *92*(3), 665-675. PMid:21035244. http://dx.doi.org/10.1016/j.jenvman.2010.10.007.

Haque, M. M., Egodawatta, P., Rahman, A., & Goonetilleke, A. (2015). Assessing the significance of climate and community factors on urban water demand. *International Journal of Sustainable Built Environment*, *4*(2), 222-230. http://dx.doi.org/10.1016/j.ijsbe.2015.11.001.

Hellegers, P., Immerzeel, W., & Droogers, P. (2013). Economic concepts to address future water supply–demand imbalances in Iran, Morocco and Saudi Arabia. *Journal of Hydrology (Amsterdam)*, *502*, 62-67. http://dx.doi.org/10.1016/j.jhydrol.2013.08.024.

Idowu, O. A., Awomeso, J. A., & Martins, O. (2012). An evaluation of demand for and supply of potable water in an urban centre of Abeokuta and Environs, Southwestern Nigeria. *Water Resources Management*, *26*(7), 2109-2121. http://dx.doi.org/10.1007/s11269-012-0006-4.

Ilaya-Ayza, A. E., Benítez, J., Izquierdo, J., & Pérez-García, R. (2017). Multi-criteria optimization of supply schedules in intermittent water supply systems. *Journal of Computational and Applied Mathematics*, *309*, 695-703. http://dx.doi.org/10.1016/j.cam.2016.05.009.

Jie, X., Yu, X., Na, L., & Hao, W. (2015). Spatial and temporal patterns of supply and demand balance of water supply services in the Dongjiang Lake Basin and its beneficiary areas. *Journal of Resources and Ecology*, *6*(6), 386-396. http://dx.doi.org/10.5814/j.issn.1674-764x.2015.06.006.

Kim, Y., Chung, E.-S., Jun, S.-M., & Kim, S. U. (2013). Prioritizing the best sites for treated wastewater instream use in an urban watershed using fuzzy TOPSIS. *Resources, Conservation and Recycling*, *73*, 23-32. http://dx.doi.org/10.1016/j.resconrec.2012.12.009.

Kumar, V., Del Vasto-Terrientes, L., Valls, A., & Schuhmacher, M. (2016). Adaptation strategies for water supply management in a drought prone Mediterranean river basin: application of outranking method. *The Science of the Total Environment*, *540*(1), 344-357. PMid:26277442. http://dx.doi.org/10.1016/j.scitotenv.2015.06.062.

Marttunen, M., Lienert, J., & Belton, V. (2017). Structuring problems for Multi-Criteria Decision Analysis in practice: A literature review of method combinations. *European Journal of Operational Research*, *263*(1), 1-17. http://dx.doi.org/10.1016/j.ejor.2017.04.041.

Matrosov, E. S., Padula, S., & Harou, J. J. (2013a). Selecting portfolios of water supply and demand management strategies under uncertainty—contrasting economic optimisation and 'robust decision making' approaches. *Water Resources Management*, *27*(4), 1123-1148. http://dx.doi.org/10.1007/s11269-012-0118-x.

Matrosov, E. S., Woods, A. M., & Harou, J. J. (2013b). Robust decision making and info-gap decision theory for water resource system planning. *Journal of Hydrology*, *494*, 43-58. http://dx.doi.org/10.1016/j.jhydrol.2013.03.006.

Medeiros, D. F. K. L., Urtiga, M. M., & Morais, D. C. (2017). Integrative negotiation model to support water resources management. *Journal of Cleaner Production*, *150*, 148-163. http://dx.doi.org/10.1016/j.jclepro.2017.02.160.

Omar, M. M. (2013). Evaluation of actions for better water supply and demand management in Fayoum, Egypt using RIBASIM. *Water Science*, *27*(54), 78–90. https://doi.org/10.1016/j.wsj.2013.12.008.

Ouda, O. K. M. (2014). Water demand versus supply in Saudi Arabia: current and future challenges. *International Journal of Water Resources Development*, *30*(2), 335-344. http://dx.doi.org/10.1080/07900627.2013.837363.

Poustie, M. S., Deletic, A., Brown, R. R., Wong, T., de Haan, F. J., & Skinner, R. (2015). Sustainable urban water futures in developing countries: the centralised, decentralised or hybrid dilemma. *Urban Water Journal*, *12*(7), 543-558. http://dx.doi.org/10.1080/1573062X.2014.916725.

Quintas-Soriano, C., Castro, A. J., García-Llorente, M., Cabello, J., & Castro, H. (2014). From supply to social demand: a landscape-scale analysis of the water regulation service. *Landscape Ecology*, *29*(6), 1069-1082. http://dx.doi.org/10.1007/s10980-014-0032-0.

Sahin, O., Bertone, E., & Beal, C. D. (2017). A systems approach for assessing water conservation potential through demand-based water tariffs. *Journal of Cleaner Production*, *148*, 773-784. http://dx.doi.org/10.1016/j.jclepro.2017.02.051.

Scholten, L., Scheidegger, A., Reichert, P., Maurer, M., & Lienert, J. (2014). Strategic rehabilitation planning of piped water networks using multi-criteria decision analysis. *Water Research*, *49*(1), 124-143. PMid:24321248. http://dx.doi.org/10.1016/j.watres.2013.11.017.

Scholten, L., Schuwirth, N., Reichert, P., & Lienert, J. (2015). Tackling uncertainty in multi-criteria decision analysis - An application to water supply infrastructure planning. *European Journal of Operational Research*, *242*(1), 243-260. https://doi.org/10.1016/j.ejor.2014.09.044.

Segrave, A. J., van der Zouwen, M. W., & van Viersen, W. (2014). Water planning: from what time perspective? *Technological Forecasting and Social Change*, *86*, 157-167. http://dx.doi.org/10.1016/j.techfore.2013.08.019.

Suriya, S., & Mudgal, B. V. (2013). Soft systems methodology and integrated flood management: a study of the Adayar watershed, Chennai, India. *Water and Environment Journal*, *27*(4), 462-473. https://doi.org/10.1111/j.1747-6593.2012.00365.x.

Urtiga, M. M., & Morais, D. C. (2015). Pre-negotiation framework to promote cooperative negotiations in water resource conflicts through value creation approach. *Journal on Decision Processes*, *3*(3), 339-356. http://dx.doi.org/10.1007/s40070-015-0052-2.

Vetschera, R., & Almeida, A. T. (2012). A PROMETHEE-based approach to portfolio selection problems. *Computers & Operations Research*, *39*(5), 1010-1020. http://dx.doi.org/10.1016/j.cor.2011.06.019.

Wang, X., Zhang, J., Shahid, S., Guan, E., Wu, Y., Gao, J., & He, R. (2014). Adaptation to climate change impacts on water demand. *Mitigation and Adaptation Strategies for Global Change*, *21*(1), 81-99. http://dx.doi.org/10.1007/s11027-014-9571-6.

Wu, F., Bai, Y., Zhang, Y., & Li, Z. (2017). Balancing water demand for the Heihe River Basin in Northwest China. *Physics and Chemistry of the Earth, Parts A/B/C*. *101*, 178-184. https://doi.org/10.1016/j.pce.2017.07.002.