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Assessment of actions to tackle the shortages of water in La Paz, Bolivia

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Abstract

Water scarcity is a persistent problem in diverse regions of the world. This study focuses on the extreme scarcity of water affecting La Paz, a municipality in the west of Bolivia. The intense drought of the last few decades and the inadequate management of water utilities have impacted several factors. Within this context, this study identified that establishing efficient water resource management is essential to guarantee social welfare. The researchers analyzed the scarcity of water in La Paz by using the Strategic Choice Approach, which is a problem structuring method based on a strategic process that takes different types of uncertainty into account. The results of this study revealed decision actions and uncertainties in two categories: the present and the future. The outputs enabled a strategic plan to be drawn up that tackles the scarcity of water responsibly and equitably. Innovation and investment in ways to reuse water are fundamental to developing a responsible solution.

Keywords: Bolivia; Strategic plan; Water management; Water scarcity

1. Introduction

La Paz, the capital of Bolivia, is a city located in western Bolivia. It is among seven other municipalities that together constitute the Metropolitan Region of the Department of La Paz (RMDLP). Geographically, La Paz is a region within a plateau called the Bolivian Altiplano, which lies nearly 3,625 m (11,811 ft) above sea level. The climate includes dry winters and rainy summers. Thus, evaporation rates tend to be higher than precipitation rates, thus causing desertification (Montes de Oca, 1997). La Paz is surrounded by plateaus, and its principal sources of water are rainwater runoff and from thawing glaciers (Hoffmann, 2013). Over the last few decades, this region has been suffering from a shortage of water. Factors that have caused this include the region having a very rugged

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topography, problems in the management of services offered by water companies, and relatively recent changes in the climate (Montaña *et al.*, 2016; Distefano & Kelly, 2017).

The demands for water arise from many common uses, including from residences, industry, and agriculture; the ecological/natural flow; and the generation of hydropower (Brunner *et al.*, 2019). Consequently, there is a strict relationship between the availability of water and the sustainable development of a region that is dependent on being able to meet people's needs (Berhanu *et al.*, 2014). Given these circumstances, Arroyo & Nuñez (2017) made proposals to reduce water insecurity that ensure the efficient use of, and access to, water resources. It is emphasized that the main factors are as follows: improving the governance of water (Pinto *et al.*, 2017), increasing efficiency in irrigated areas and dry farming, reducing levels of pollution in surface water, increasing ways to protect the watershed, and consolidating the management of sustainable sources of groundwater.

A gap in the balance between the demand for, and the availability of, water is notable in many regions of Europe, including Romania (Mitrică *et al.*, 2017) and Switzerland (Brunner *et al.*, 2019), as well as in other nations around the world, such as Sub-Saharan Africa (Lanzanova *et al.*, 2019), Iran (Chitsaz & Azarnivand, 2017), and Brazil (Gonçalo & Morais, 2018). The need to establish clear improvements in water supply systems (WSSs) is present in campaigns that seek to raise public awareness of this issue. Within this context, Saz-Salazar *et al.* (2015) conducted a study in Sucre, a city in Bolivia, using the willingness-to-pay technique. These researchers found that most households would be willing to pay an additional fee in their bill to have a more continuous and reliable water service.

The complexity of decision-making on water resources is due to there being various stakeholders and conflicting objectives involved (Chitsaz & Azarnivand, 2017). Carvalho *et al.* (2012) conducted a study based on the meta-regression analysis, which pointed out issues such as the need for economies of scale and reaching agreement on the scope of water management. They suggested that diseconomies of scale and scope are more likely to be found in publicly owned utilities than when the ownership of utilities is private. A proposal to improve a system requires an understanding of several elements, such as its organizational structure, processes, procedures, internal and external interrelations, and communication mechanisms (Smith & Shaw, 2019). From this perspective, problem structuring methods (PSMs) offer a good approach. These methods are effective for identifying tangible solutions because they improve how information is synthesized and give an overview of the (internal and external) issues involved in the situation. Specifically, the Strategic Choice Approach (SCA) can be differentiated from other PSMs due to the possibility of its considering uncertainties in the analysis and of providing results from two time perspectives: the present and the future (Friend, 2001).

This paper is organized into six sections including this introduction. In Section 2, the SCA approach to the problem is described. In Section 3, the problem is defined. In Section 4, the methodological procedure describing how the SCA is aligned with the characteristics of water scarcity and shortages is presented. In Section 5, data from the case study are analyzed and the results are discussed in Section 5.1. Finally, the authors draw some conclusions and make recommendations for future lines of study.

2. SCA approach

In summary, PSMs are qualitative approaches that enable nonstructured problems to be represented and to make advances. PSMs are classified as soft operational research (OR) approaches, which, in analytical processes, include using intangible information as input and which consider different perspectives that can be partially conflicting (Mingers, 2011). Smith & Shaw (2019) conducted a review that highlights some PSMs, such as Strategic Options Development and Analysis, Soft Systems Methodology, and the SCA.

The SCA has four phases (shaping, designing, comparing, and choosing) and identifies mutually compatible actions that are consistent with the scenario predicted (Fregonara *et al*., 2016). It is a cyclical and flexible process and thus allows decision makers (DMs) to return to previous phases whenever adjustments are needed. The SCA has prompted advances in several fields of study as evidenced in the literature, such as energy-efficient buildings, design projects (Fregonara *et al*., 2016), educational planning (Phahlamohlaka & Friend, 2004), architecture (Todella *et al*., 2018), and water basins (Levino & Morais, 2013).

Within the context of water supply, it is essential that DMs' knowledge and experiences be used in order that efficient results are achieved. Hence, this study proposes a methodological framework based on the SCA. In the initial phase, a brainstorming technique was used to help creative ideas for tackling the problem to be generated and developed. A real application for La Paz was presented, which was implemented in an interactive and dynamic way to evaluate, compare, and define economic and socio-environmental decisions that would lead to minimizing shortages of water. The parameters and decision results were obtained by aggregating the preferences of the four DMs: a representative of a local community, a land surveyor, a government employee, and an expert in environmental management. This study contributes to establishing a more comprehensive understanding of the problem of the scarcity and shortages of water in La Paz and offers a strategic plan that can draw up possible solutions for this problem from present and future time perspectives.

3. Defining the problem

La Paz municipality, the capital of La Paz state, is located in the Province of Pedro Domingo Murillo. It has a population of 812,799 inhabitants distributed over 3,040 km² (INE, 2012). La Paz has a peculiar topography; it is surrounded by the altiplano (a plateau), similar to a canyon. The Cordillera Real (also known as Cordillera de La Paz) can be seen from the city, with the prominence of the Nevado Illimani (an average altitude of 6,402 m). The region has seasonal variations in temperature and a cold climate, characterized by a mean annual temperature of 14 °C, as well as rainy summers and dry winters. The average annual rainfall is 575 mm, precipitation being mainly concentrated between the months of December and April (GAMLP, 2019).

The western limit of La Paz municipality is El Alto. They used to form a single municipality. This explains the complementarity of the production and distribution of water in this region. The main WSS consists of three subsystems: Milluni-Achachicala, Hampaturi-Pampahasi, and Tilata-El Alto (Hardy, 2013), as shown in Figure 1. Carvalho *et al*. (2012) point out that the topology of the area is a factor that increases the complexity in building and maintaining water networks.

In relation to the subsystem presented in Figure 1, the Pampahasi station is responsible for providing water to the neighborhood of Miraflores. Communities located in eastern and south of La Paz receive water from three dams: Incachaca, Hampaturi, and Ajuankhota (Hardy, 2013). The Achachicala station supplies the center of La Paz. The sources of water of this station are the extremely polluted Choqueyapu River, the Ajuankhota dam (a natural reservoir with good quality water from rainfall and glaciers), and the Milluni dam (an artificial reservoir that is polluted with heavy metals released into

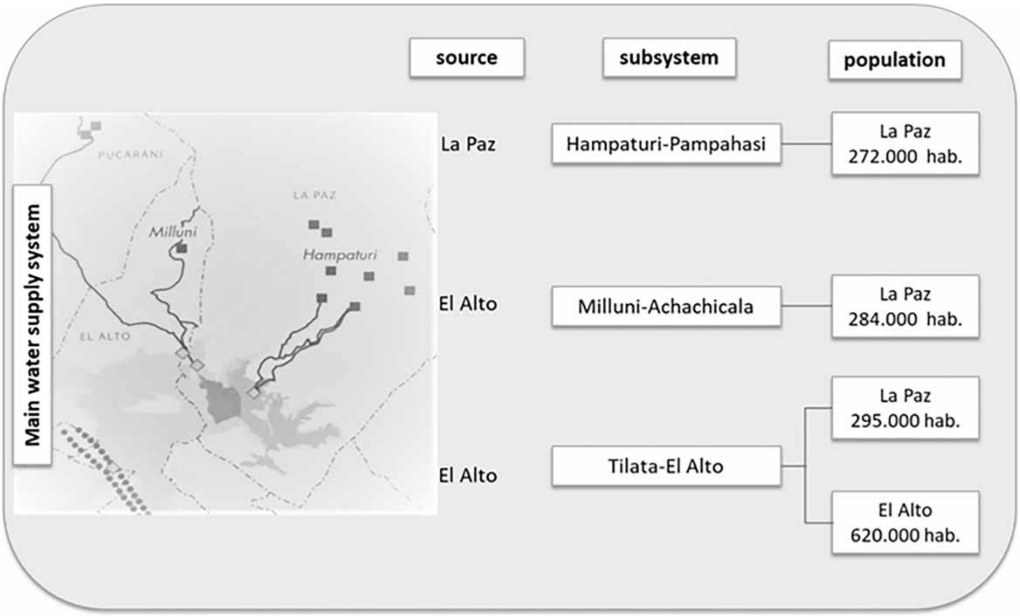


Fig. 1. Operation of the main WSS (adapted from Hardy, 2013).

it by the mining industry) (Hoffmann, 2013). Moreover, the station of El Alto supplies the neighborhoods located on the western slopes of La Paz. The water is made drinkable by the Tilata station and also comes from wells that collect water from the water table (Hardy, 2013).

The water supply in La Paz essentially depends on the surface runoff from rainfall and glaciers. However, ever since the 1980s, due to disorganized agricultural practices and changes in the climate, Andean glaciers have been losing mass, causing serious natural problems such as shortages in the supply of water to peri-urban areas (Rangecroft *et al*., 2015; Saz-Salazar *et al*., 2015).

Overall, the reasons for the scarcity of water in the municipality of La Paz include the loss of flora which has increased the risk of desertification, topological features of the area (peaks with high altitudes), improvised urbanization resulting from the growth in the population and from rural migration, a lack of investment in public policies, and decision-making processes that do not include the objectives of all DMs. Moreover, other matters that must also be taken into account include extractive activities, deficiencies in prospecting and quantifying groundwater resources, and high rates of water loss (Montes de Oca, 1997; Hoffmann, 2013).

In November 2016, La Paz faced its largest water crisis of the last 25 years. The volume of water held in three major reservoirs – Incachaca, Hampaturi, and Ajuan Khota – fell to 8%, 5%, and 1% of their capacity, respectively. The authorities had to declare a state of emergency. Consequently, and unusually, 340,000 people in more than 100 middle-class neighborhoods were affected. This caused the rationing of water to be last for several weeks (Página Siete, 2016). Moreover, the change in pressure in the pipes, due to the scarcity of water, led to five distribution channels bursting. Contributory factors included there having been a lack of adequate maintenance and the incapacity of the public network operators. However, the main reason for the near collapse of the system was that it has aged, and this fact alone causes a loss of up to 60% of the potable water.

4. Methodology

The SCA is a process developed by John Friend during the 1970s to understand and structure problems by establishing a compromise plan with actions to be realized in the present and the future. The SCA allows both qualitative and quantitative attributes to be evaluated and uncertainties to be taken into consideration. According to Friend & Hickling (2005), the SCA involves including policies for managing conflicts in its structure. Furthermore, this approach can be characterized as a set of graphical problem structuring tools that create a transparent guide, so that a working group of DMs can draw up and agree upon action planning (Phahlamohlaka & Friend, 2004).

The SCA, dynamically, presents four complementary 'modes': shaping (defining inputs to structure the problem), designing (determining a focus for the problem), comparing (comparing possible actions using evaluation criteria), and choosing (agreeing on preferences to determine the strategic planning) (Friend & Hickling, 2005). These modes enable a subset of cohesive actions to be identified and together form the strategic plan that will address and hopefully solve the decision problem. Friend (1990) presents the SCA's main advantages:

- The SCA focuses on the decisions to be made in a planning context. In general, strategic decisions present complex links, which can result in some difficulties for the DMs when trying to reach an understanding of and to model the problem situation.
- The approach enables judgments to be made on uncertainties that affect decisions. This point increases the level of confidence in the process because, by managing uncertainty, the setting of goals can be determined and modeled and therefore lead to actions that are grounded on these factors.
- The SCA is an incremental and progressive method that expresses its results in a 'commitment package,' rather than one determination of a single strategic solution. The results represent a balance between decisions and uncertainties to be tackled now and in the future.
- It is an interactive approach and, consequently, using it does not require specialized knowledge.

Briefly, the SCA considers three types of uncertainties, as set out below (Friend, 1990; Friend & Hickling, 2005):

- Uncertainties about the working environment (UE): these require interventions for the purposes of analysis, such as research, forecasting, or modeling.
- Uncertainties about guiding values (UV): these require policy actions, such as the definition of objectives and consultation with stakeholders.
- Uncertainties about related choices (UR): these require some kind of negotiation or collaboration because these aspects exceed the limits of the current decision.

In the present study, the brainstorming technique was aligned with the SCA to improve the generation of ideas. Figure 2 represents the proposed methodological framework.

The framework (Figure 2) is based on the knowledge, experience, and preferences of each DM involved in the process. The workshop is characterized by a group dynamic that uses brainstorming and aims to provide a creative environment in which the solution to the problem will be planned. The principles of brainstorming enhance the quality and innovativeness of generating ideas in a group. It is also an opportunity to discuss the key elements of the SCA (decision area, comparison

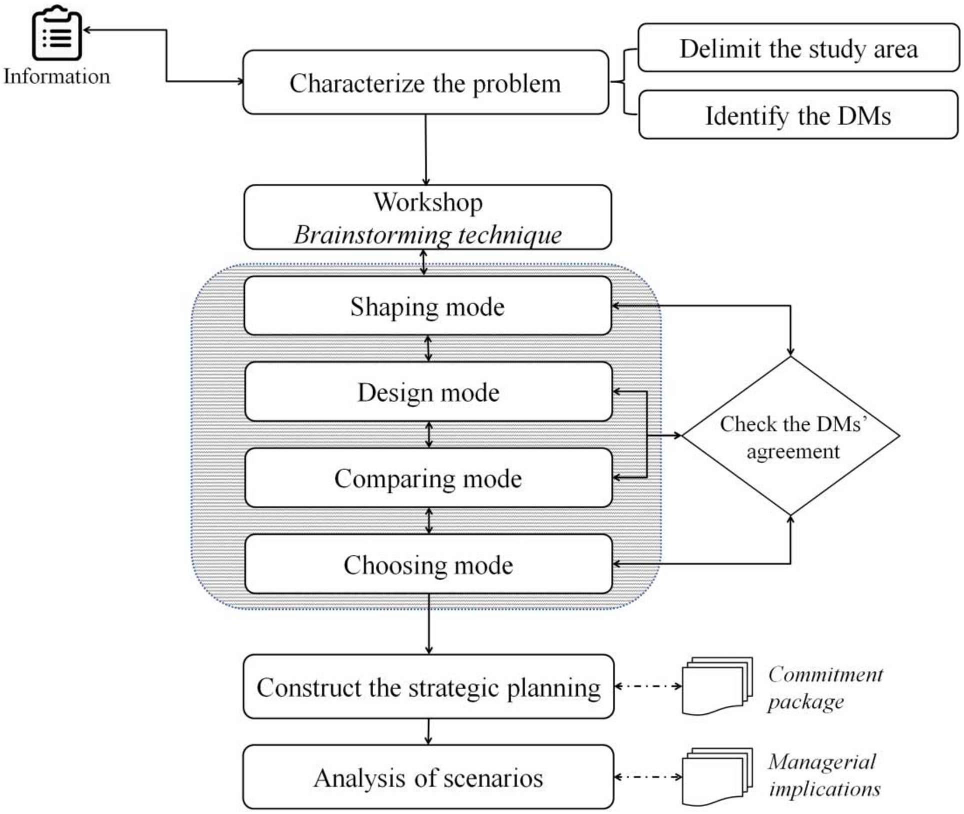


Fig. 2. Flowchart of the proposed model. The shaded area represents the SCA phases.

area, and uncertainty area) (Friend & Hickling, 2005). Thereafter, the four SCA phases are developed, and the process for this consists of strategic planning, in which the analysis of scenarios increases knowledge about possible solutions to the problem. Thus, what can be identified are actions to improve efficiency, guarantee water supply, and improve the wellbeing and quality of life for the La Paz population, especially as a result of the analysis of scenarios.

5. Case study

Firstly, the DMs were identified (Figure 2). The water scarcity context has a multi-perspective feature, and consequently, more than one representative view was taken, as set out below:

- A researcher and land surveyor of *Universidad Mayor de San Andrés* as a representative of the *Gobierno Autónomo Municipal de La Paz* (GAMLP).
- A resident and community leader of the study area.
- An expert in environmental management as a representative of a water company: *Empresa Pública Social de Agua y Saneamiento S.A.* (EPSAS S.A.).
- A public sector manager as a representative of the *Ministério de Medio Ambiente y Agua* (MMAyA).

In this proposed framework, the facilitator's role is essential. The facilitator is an actor responsible for the guidelines of the entire process and promotes learning without imposing preferences and values on the process. In this study, the software Strategic Adviser (STRAD version 2.3), developed by Stradspan Limited, was used as support.

In the initial workshop, using Alex Osborn's *Principles and Procedures of Creative Problem Solving* (Osborn, 1953) for group meetings, the brainstorming session began with discussing the purpose of improving the exchange of knowledge about the decision problem. Thus, the four DMs met for approximately one and a half hours and engaged on discussing an intense flow of information. The sharing of objectives and requirements by the DMs resulted in the prior structuring of SCA input being conducted in a pleasant and nonconfrontational way.

Given this scenario, the shaping mode is used to present the inputs for the SCA process. Consequently, DMs are concerned with comprehending the decision problem (Levino & Morais, 2013). Matters that must be established include the decision areas that represent opportunities for exploration; the DMs' respective decision options, which constitute the essential action points for each decision area; the comparison areas that lead to issues concerned with the judgment of actions; and the areas of uncertainty. Each of these inputs is linked to a label which facilitates and simplifies identification. Thus, the DMs reached agreement on seven decision areas which they identified as important opportunity points for tackling the scarcity of water and minimizing shortages in La Paz. These are listed below (the question mark indicates that the key word is the label given to a decision area).

- Seasonal water rationing (SEASONAL?) represents the setting of rigorous water rationing for all types of consumers (residential and nonresidential) based on seasonal variations (Qahtani *et al.*, 2016).
- Investments in groundwater exploration (GROUNDWATER?) represent the construction of new catchment points and the improvement of current extraction technologies (Hardy, 2013).
- A decrease in the impacts of agricultural activities (AGRICULTURE?) represents the consequences of disorganized agriculture practices, including the burning of plantations that make glaciers dark, which results in their not reflecting the sun's rays and thawing faster (Hoffmann, 2013).
- Investments in water reuse (INVEST_REUSE?) represent ways to recycle water (Mierzwa & Hespanhol, 2005).
- Tariff modification (TARIFF?): tariff escalation related to the consumption category (Saz-Salazar *et al.*, 2015, Qahtani *et al.*, 2016).
- Water loss reduction (LOSS?) represents improved maintenance management in the water distribution system to correct and avoid leakages (Trojan & Morais, 2015).
- Investments in the distribution network system (DISTRIBUTION?) represent the expansion of the network extension and the assessment of consumer behavior (Hardy, 2013).

Table 1 details relevant decision options for each decision area described. In practice, for each decision area, at least two nonredundant and available actions must be identified based on agreement among the DMs. It is important to highlight that the debate was intense because different perceptions emerged about the number of options in each decision area.

Table 1. Decision options.

Decision area	Decision options	Label
SEASONAL?	(a) Set strict water rationing in rainy periods	_PRECIPI
	(b) Set strict water rationing in dry periods	_DESERTI
GROUNDWATER?	(c) Improve groundwater recharge management	_RECHARGE
	(d) Increase the number of water wells	_WELL
AGRICULTURAL?	(e) Restructure agricultural activities in the southern region	_SOUTH
	(f) Restructure agricultural activities in the northern region	_NORTH
	(g) Restructure agricultural activities in the eastern region	_EAST
INVEST/REUSE?	(h) Establish project to improve the direct reuse of water	_DIRECT
	(i) Establish project to improve the indirect reuse of water	_INDIRECT
	(j) Establish project to minimize the volume of the reuse nonpotable water	_NON_POTABLE
TARIFF?	(k) Restructure commercial water service tariffs	_COMMERCIAL
	(l) Restructure domestic water service tariffs	_DOMESTIC
	(m) Restructure industrial water service tariffs	_INDUSTRIAL
LOSS?	(n) Install a remote telemetry system in the distribution system	_TELEMETRY
	(o) Establish a structure to implement a smart water system	_SMART_WATER
	(p) Install flow valves in the distribution system	_FLOW
DISTRIBUTION?	(q) Replace old cement pipes with PVC pipes	_PIPES
	(r) Determine strategic networks for predictive maintenance	_STRATEGIC
	(s) Set up monitoring in the supply system using sectorization	_MONITORING

Five comparison areas were identified, which represent desired points to assess the decision options (Friend & Hickling, 2005). These aspects are similar to the criteria concept in a multi-criteria approach. These aspects are as follows:

- Capital investment (COST): a minimization criterion that represents the amount of financial resources required to implement the decision option.

- EPSAS S.A.'s profits (CASH): a maximization criterion that consists of the additional profits that the water company will receive due to implementing and maintaining the decision option.
- Number of beneficiary consumers (CONS_NUMBER): a maximization criterion that represents the number of consumers who will benefit from the decision option being implemented.
- Mensuration of water quality (WATER_QUALITY): a qualitative and maximization criterion that analyzes the level of water quality that the decision option can provide to consumers.
- Mensuration of water quantity (WATER_QUANTITY): a maximization criterion that measures the additional volume of water that will be obtained by implementing the decision option.

However, in the debate, issues such as technology and environmental impacts were also raised. During the brainstorming session, some ideas from each sector initially seemed unacceptable, but it is by debating ideas that understanding and acceptance of proposals can be reached. For example, the DM expert in environmental management, as the representative of a water company, proposed applying a table of tariffs for water consumption based on a usage limit. In other words, he proposed the restructuring of the domestic tariff for water services. Another DM, a resident and community leader of the study area, saw little benefit arising from this proposal because such a restructuring would adversely affect the cost of living of the population, but it became clear from the discussions that the tariff would increase only if the limit were exceeded, and that this would be defined after conducting a study that would determine what a reasonable amount of use per day was. This generates understanding, agreement, and better proposals. Given the current difficulties faced in the locality and budgetary restrictions, these issues were not considered priority ones.

Uncertainty concerns issues which are classified as doubts or conflicts arising from the context of the problem. For each uncertainty, an assessment is required based on its level of prominence (i.e., an evaluation of how easy or difficult it is to identify the uncertainty) and the level of treatability (i.e., an evaluation of how easy or difficult it is to minimize the uncertainty) (Friend & Hickling, 2005). To evaluate the description of each uncertainty area, the Likert scale can be used to establish the level of uncertainty. This ranges from 1 (low level) to 5 (high level). In this case study, four issues were identified, which are described below.

- Policy importance of investment (?POLITIC) – UV type represents the uncertainty aspect of political support to achieve investment in the WSS. Political support can also be understood as establishing partnerships with suppliers, research institutions, or even community leaders. This uncertainty received an evaluation of three for prominence and two for treatability.
- Future trends in population (?CONSUMER) – UR type represents the uncertainty of there being a trend toward raising consumers' awareness of the need to use water rationally. This uncertainty received an evaluation of four for prominence and three for treatability.
- Importance of the agricultural sector for the economy (?ECONOMY) – UV type represents the uncertainty of demand, i.e. whether it will grow or shrink, due to the impact of policy and economic factors. Climate changes also influence this. This uncertainty received an evaluation of three for prominence and two for treatability.
- Projection of population growth (?GROWTH) – UE type represents the uncertainty about whether the demand of households will grow. This uncertainty received an evaluation of four for prominence and four for treatability.

Table 2. Assessment of the impact of exploration actions under different criteria.

Uncertainty area	Exploration actions	Label	Criteria		
			Cost	Delay	Gain
?POLITIC	Establish a relationship with community leaders	Community	1	3	3
	Present innovative projects and bid for funding	Innovation	3	4	3
	Establish partnerships with suppliers and research institutions	Relationship	1	2	4
?CONSUMER	Conscious use of socialization	Rational use	2	2	4
	Create water education programs in schools	Education	1	3	5
	Ensure compliance with water protection laws	Laws	2	4	3
?ECONOMY	Determine adjustments and draft laws	Econ_adjust	3	5	3
	Encourage the implementation of new activities in the sector	Campaigning	5	3	4
?GROWTH	Investment in public policies	Investment	4	3	4
	Update the database	Survey	2	3	2

Exploration actions are assessed based on three issues, according to Friend & Hickling (2005). These are the cost of an option (adjusting monetary values or the opportunity cost), delay (the amount of time needed to search for the option in urgent decision-making), and gain (expected confidence by reducing the uncertainty). Table 2 presents the actions for each type of uncertainty.

The design mode needs a problem focus. In other words, a decision problem usually involves many decision areas, and in order to conduct an efficient analysis, some issues must be prioritized, i.e. a focus must be established (Friend & Hickling, 2005). Thus, a decision graph (see Figure 3(a)) is assembled to provide a visualization of the interconnections of decision areas. In this graph, the problem focus consists of decision areas, which are delimited by a dotted line. The decision areas, which are in bold, were highlighted by the DMs and therefore are of greater importance. Moreover, a rich and manageable set of acceptable solutions is generated, which take uncertainties into account. The DMs discuss and seek to reach agreement on what courses of action should be taken and that preferably these actions can be taken independently of each other. Nevertheless, they need to be integrated into a plan and to do this, a compatibility index is used and is complemented by the DMs using an options tree (see Figure 3(b)).

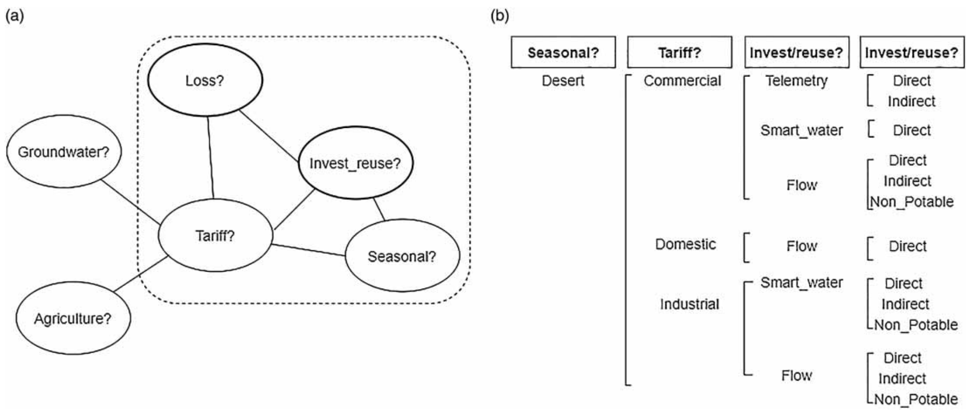


Fig. 3. (a) Decision graph and problem focus and (b) decision tree.

In the comparison mode, the consequences of the different courses of action were compared to one another during which the evaluation criteria were taken into consideration. This resulted in determining the consequences, effects, and implications for each action. When analyzing the decision areas for each comparison area, some relationships were identified. Thus, the GROUNDWATER area has a great impact on the 'Cost' criterion; the greatest influence of the INVEST-REUSE area is on the 'Cons_number' criterion; and the AGRICULTURAL area has a large effect on the 'Water_quality' criterion. Moreover, two criteria influence more than one decision area. This situation applies to the 'Cash' criterion, which has a greater impact on the LOSS and TARIFF areas, and the 'Water_quantity' criterion, which influences the DISTRIBUTION and RACIONAM areas. These relationships were obtained after intense discussion among the four DMs in order to establish a consensus.

Finally, in the choosing mode, the results of the SCA are shown in a progress package (see Table 3), which correspond to the result of Scenario 1. Therefore, it determines the commitment to accountability that each DM will accept for the action plan, which can be implemented now or in the future. This progress package can be used as input for management planning.

According to Table 3, the progress package recommends immediate interventions of decisions related to water rationing in periods of low precipitation rates, direct investment in water reuse, and changes in the tariffs charged to domestic consumers. Treatment and water reuse also have importance in a study developed by Flores *et al*. (2018) in El Bajío, Mexico, which used the analytical hierarchy process to identify management priorities. Moreover, two uncertainties need priority attention. One is related to improving policy projects based on the innovation level, and another is to mount water awareness campaigns. The points classified as belonging to the future perspective must be understood as contingent for a future agenda (Friend & Hickling, 2005). These points are subject to being dealt with flexibly, as this will depend on the results of implementing current actions, and it is possible to include additional constraints.

5.1. Discussion

The water scarcity problem is growing in the most diverse regions of the world (Gonçalo & Morais, 2018). In recent years, scientific attention on the scarcity and shortage of water has significantly increased due to climate change and population growth. The management of water scarcity is concerned with controlling losses, water reuse, and improving innovations in alternative solutions. Our contribution attempts to identify the best strategic actions to minimize the water scarcity problem in La Paz.

The results presented in Table 3 can be used as input to establish strategic planning, which is responsible for coordinating and evaluating activities required to achieve each point of the guideline (i.e., the

Table 3. Progress package.

	NOW		FUTURE	
Sector	DECISIONS: actions	UNCERTAINTIES: explorations	DECISIONS: actions	UNCERTAINTIES: explorations
EPSAS	Seasonal?_Deserti			?Economy
MMAyA	Invest_reuse?_Direct	?Politic_Inovation		
GAMLP	Tariff?_Domestic	?Consumer_Rational use	Loss?	?Growth

Table 4. Short-term strategic planning for minimizing water scarcity in La Paz municipality.

Decision areas			
Decision action	Activities	Achievement indicator	Schedule time
Seasonal?_Deserti	Encourage reforestation and increase social awareness related to the preservation of green areas	Percentage of green areas in m^2 in relation to the region	40 months
	Water rationing programs	Volume of water saved	12 months
Invest_reuse?_Direct	Provide training and materials for consumers to adapt to water reuse	Volume of water in treatment plants	16 months
	Create a project for determining mandatory direct water reuse in administrative public offices	Evolution of the number of administrative public offices adapted	18 months
Tariff?_Domestic	Water tariffs adjusted based on the consumer economic level	Water default rates	8 months
	Establish a continuous bonus program for evolving a reduction in the consumption of water	Number of consumers; volume of water saved per participant	10 months
Areas of uncertainty			
Uncertainty action	Activities	Achievement indicator	Schedule time
Politic_Inovation	Establish an interinstitutional committee on water technology and innovation	Number of projects evaluated and approved	10 months
	Determine a set of innovation criteria (radical or incremental)	Number of projects evaluated and approved	15 months
	Establish university partnerships	Number of partnerships	15 months
Consumer_rational use	Draw up and mount awareness-raising campaigns on how to use water rationally	Number of awareness campaigns mounted	4 months
	Promote courses on using water aimed at improving its efficient consumption	Number of courses held	6 months
	Provide low-income consumers with the raw materials needed to repair pipes	Number of consumers helped	11 months

now perspective of the package matrix). Table 4 presents related activities and achievement indicators which were drawn up by a project committee which consisted of members of GAMLP and EPSAS S.A.

The focus of the problem can be modified based on the inclusion or substitution of decision areas in order to obtain new scenarios in the decision process. Being able to do this demonstrates why the SCA is more appropriate than other methods. Consequently, it enables interaction, not necessarily in sequential modes, to take place; information already held to be recycled; and the level of comprehension of the problem to be deepened and widened. In this context, two new problem focuses develop. The scenario analysis improves knowledge about the impacts of the commitment package because this analysis can take previously unrecognized factors into consideration and, secondly, adjacent decision areas can be re-assessed.

From this perspective, Scenario 2 proposes a problem focus which also consists of four decision areas. However, two decision areas differ from the initial evaluation (Groundwater and Agricultural). Figure 4 gives an overview of how the model proposed is applied.

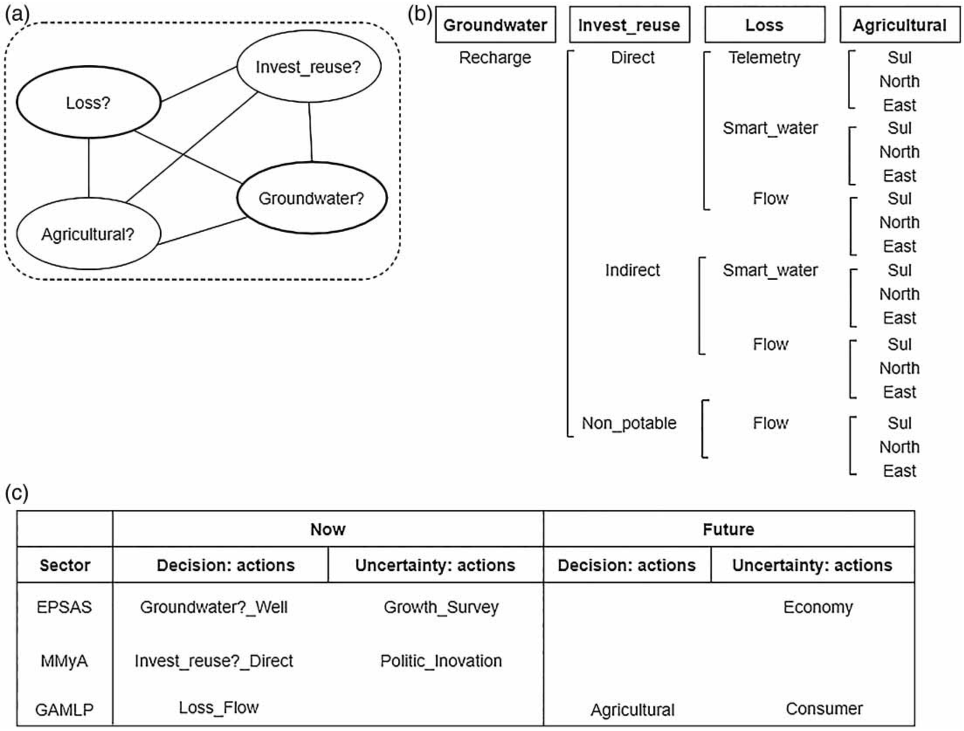


Fig. 4. Scenario 2. (a) Decision graph, (b) combinations of decision tree, and (c) progress package.

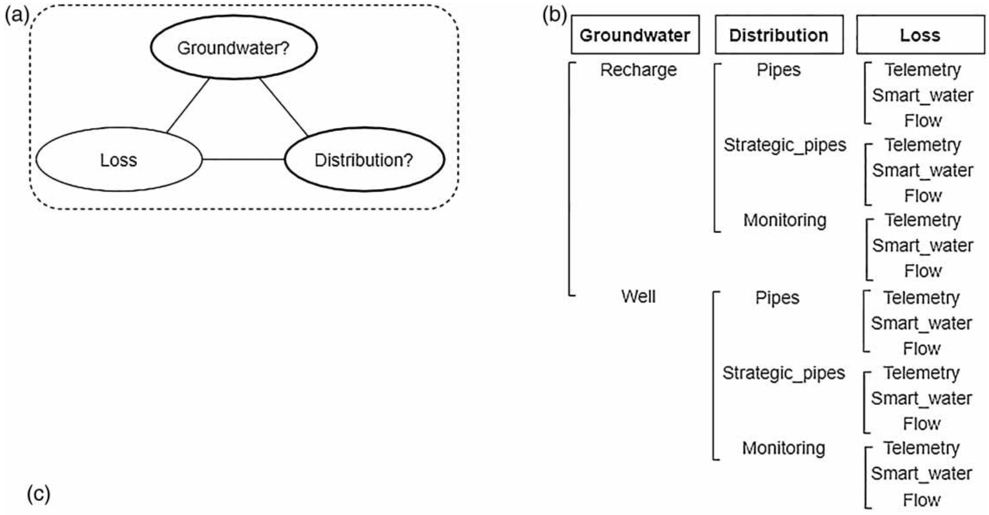
According to the results shown in Figure 4, the consensus among the DMs determined priority areas as three actions: the construction of a new well for catchment groundwater, investing in the direct reuse of water, and installing flow valves in the distribution system.

In addition, Scenario 3 was proposed. In this case, the problem focus is based on three decision areas, which concern investment in groundwater, investment in the distribution network, and the reduction of physical water losses, as shown in Figure 5.

Therefore, the results evidenced within the commitment packages obtained from the evaluation of the different problem focuses allow for a subtle perception of the differences in the proposed sets of actions in terms of impact and time of implementation. These details aim to improve the planning of strategies with the purpose of obtaining greater comprehensiveness in the quest to add to and improve the quality of life for the population of the La Paz region.

6. Conclusions

In Bolivia, managing water resources has to contend with many problems, and this task has been made even more difficult because of the lack of decision-making processes that can deal with complex situations. In addition, the sectors are not integrated, and consequently, decisions are made in an improvised, provisional manner and include some subjective values. This paper has presented a soft OR model which is designed to aid the municipality of La Paz to plan



(c)

	Now		Future	
Sector	**Decision: actions**	**Uncertainty: actions**	**Decision: actions**	**Uncertainty: actions**
EPSAS		Growth_Survey		Politic
MMyA	Groundwater?_Well			
GAMLP	Distribution?_Pipes	Economy_Campaing	Loss?_Smart_water	Consumer

Fig. 5. Scenario 3. (a) Decision graph, (b) combinations of decision tree, and (c) progress package.

how to tackle water scarcity under an SCA perspective. In this study, the main difficulties presented in the WSS of La Paz were identified. Thus, issues that arise due to the absence of a preventive public policy include the rates of the physical loss of water are high; pollution due to agricultural activities is uncontrolled; there is an absence of planning with respect to population growth and urbanization; a culture of using water resources efficiently is lacking; and topographic features of La Paz and its surroundings are difficult to overcome and solutions for these need to be analyzed in greater depth.

The use of the SCA is feasible because it has been proved that it offers an adequate approach for dealing with states of emergency. The improvement of conflicting aspects justifies its use due to its being adaptable to the problem under study. From a future perspective, an opportunity is to apply this framework in different regions of Bolivia in order to obtain global solutions for how best to tackle water scarcity. Moreover, aligning the SCA outcomes with other methods and tools for decision support can lead to priority management actions being refined.

Conflict of interest

The authors declare that they have no conflict of interest.

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References

Arroyo, J. & Nuñez, J. (2017). *Atlas de la Región Metropolitana del Departamento de La Paz*. Gobierno Autónomo Municipal de La Paz, Universidad Mayor de San Andrés. La Paz, Bolivia, SPC Impresores S.A.

Berhanu, B., Seleshi, Y. & Melesse, A. M. (2014). Surface water and groundwater resources of Ethiopia: potentials and challenges of water resources development. In: *Nile River Basin*. Melesse, A., Abtew, W. & Setegn, S. (eds). Springer, Cham, pp. 97–117. https://doi.org/10.1007/978-3-319-02720-3_6.

Brunner, M. I., Gurung, A. B., Zappa, M., Zekollari, H., Farinotti, D. & Stähli, A. (2019). Present and future water scarcity in Switzerland: potential for alleviation through reservoirs and lakes. *Science of the Total Environment 666*, 1033–1047. https://doi.org/10.1016/j.scitotenv.2019.02.169.

Carvalho, P., Marques, R. & Berg, S. (2012). A meta-regression analysis of benchmarking studies on water utilities market structure. *Utilities Policy 21*(1), 40–49. https://doi.org/10.1016/j.jup.2011.12.005.

Chitsaz, N. & Azarnivand, A. (2017). Water scarcity management in arid regions based on an extended multiple criteria technique. *Water Resources Management 31*, 233–250. https://doi.org/10.1007/s11269-016-1521-5.

Distefano, T. & Kelly, S. (2017). Are we in deep water? Water scarcity and its limits to economic growth. *Ecological Economics 142*, 130–147. http://dx.doi.org/10.1016/j.ecolecon.2017.06.019.

Flores, H., Morales, J. L., Mora-Rodríguez, J., Carreño, G. & Delgado-Galván, X. (2018). Management priorities for aquifers in El Bajío in Guanajuato state, Mexico. *Water Policy 20*(6), 1161–1175. https://doi.org/10.2166/wp.2018.202.

Fregonara, E., Giordano, R., Rolando, D. & Tulliani, J.-M. (2016). Integrating environmental and economic sustainability in new building construction and retrofits. *Journal of Urban Technology 23*(4), 3–28. https://doi.org/10.1080/10630732.2016.1157941.

Friend, J. (1990). Planning concepts, planning contexts. *Systems Practice 3*, 195–206. https://doi.org/10.1007/BF01060882.

Friend, J. (2001). The strategic choice approach. In: *Rational Analysis for a Problematic World Revisited*, 2nd edn. Rosenhead, J. & Mingers, J. (eds). John Wiley & Sons Ltd, Chichester, Chapter 6.

Friend, J. & Hickling, A. (2005). *Planning Under Pressure: The Strategic Choice Approach*, 3rd edn. Pergamon, Oxford.

GAMLP (2019). *La Paz: ciudad maravilla* (wonder city). Available at: https://www.lapaz.bo/lapazmaravillosa (accessed May 5 2019). La Paz Government.

Gonçalo, T. E. E. & Morais, D. C. (2018). Group multicriteria model for allocating resources to combat drought in the Brazilian semi-arid region. *Water Policy 20*(6), 1145–1160. https://doi.org/10.2166/wp.2018.034.

Hardy, S. (2013) *Atlas de la vulnerabilidade de la aglomeración de La Paz (Vulnerability Atlas of the La Paz Agglomeration),* 1st edn. Plural Editores, La Paz, Bolivia, 2009–2013.

Hoffmann, D. (2013). *Cambio climático en Bolivia (Climate Change in Bolivia)*. Instituto Boliviano de la Montaña, 2011–2013.

INE. Censo Demográfico (2012). *Demographic Census 2012*. Available at: http://censosbolivia.ine.gob.bo/webine/content/la-paz-por-municipios-cnpv-2012 (accessed April 25 2019).

Lanzanova, D., Whitney, C., Shepherd, K. & Luedeling, E. (2019). Improving development efficiency through decision analysis: reservoir protection in Burkina Faso. *Environmental Modelling and Software 115*, 164–175. https://doi.org/10.1016/j.envsoft.2019.01.016.

Levino, N. A. & Morais, D. C. (2013). Applying Strategic Choice Approach for decision making of watersheds committees. In: *IEEE International Conference on Systems, Man and Cybernetics*, Manchester, UK. https://doi.org/38-43.10.1109/SMC.2013.14

Mierzwa, J. C. & Hespanhol, I. (2005). *Água na indústria: uso racional e reuso (Water in Industry: Rational Use and Reuse)*. Oficina de Textos, São Paulo.

Mingers, J. (2011). Soft OR comes of age – but not everywhere! *Omega 39*(6), 729–741. https://doi.org/10.1016/j.omega.2011.01.005.

Mitrică, B., Mitrică, E., Enciu, P. & Mocanu, I. (2017). An approach for forecasting of public water scarcity at the end of the 21st century, in the Timiş Plain of Romania. *Technological Forecasting and Social Change 118*, 258–269. https://doi.org/10.1016/j.techfore.2017.02.026.

Montaña, E., Diaz, H. P. & Hurlbert, M. (2016). Development, local livelihoods, and vulnerabilities to global environmental change in the South American Dry Andes. *Regional Environmental Change 16*(8), 2215–2228. https://doi.org/10.1007/s10113-015-0888-9.

Montes de Oca, I. (1997). *Geografía y recursos naturales de Bolivia (Geography and Natural Resources of Bolivia)*, 3rd edn. Edobol, La Paz, Bolivia.

Osborn, A. F. (1953). *Applied Imagination: Principles and Procedures of Creative Problem Solving*. Charles Scribner's Sons, New York, USA.

Página Siete (2016). Water crisis: La Paz suffers the worst drought in the fourth century (in Spanish). Pagina Siete, December 19, 2016. Available from: https://www.paginasiete.bo/especial01/2016/12/19/crisis-agua-sufre-peor-sequia-cuarto-siglo-120657.html#! (accessed January 20 2018).

Phahlamohlaka, J. & Friend, J. (2004). Community planning for rural education in South Africa. *European Journal of Operational Research 152*(3), 684–695. https://doi.org/10.1016/S0377-2217(03)00066-3.

Pinto, F. S., Simões, P. & Marques, R. C. (2017). Raising the bar: the role of governance in performance assessments. *Utilities Policy 49*, 38–47. https://doi.org/10.1016/j.jup.2017.09.001.

Qahtani, S. A., Sobhy, I. & Sofian, B. (2016). The impact of reforming municipal water tariff on water rationing and consumer welfare in Saudi Arabia. *Journal of Water and Climate Change 7*(4), 788–795. https://doi.org/10.2166/wcc.2016.136.

Rangecroft, S., Harrison, S. & Anderson, K. (2015). Rock glaciers as water stores in the Bolivian Andes: an assessment of their hydrological importance. *Arctic, Antarctic, and Alpine Research 47*(1), 89–98. https://doi.org/10.1657/AAAR0014-029.

Saz-Salazar, S., González-Gómez, F. & Guardiola, J. (2015). Willingness to pay to improve urban water supply: the case of Sucre, Bolivia. *Water Policy 17*(1), 112–125. https://doi.org/10.2166/wp.2014.195.

Smith, C. M. & Shaw, D. (2019). The characteristics of problem structuring methods: a literature review. *European Journal of Operational Research 274*(2), 403–416. https://doi.org/10.1016/j.ejor.2018.05.003.

Todella, E., Lami, I. M. & Armando, A. (2018). Experimental use of Strategic Choice Approach (SCA) by individuals as an architectural design tool. *Group Decision and Negotiation 27*(5), 811–826. https://doi.org/10.1007/s10726-018-9567-9.

Trojan, F. & Morais, D. C. (2015). Maintenance management decision model for reduction of losses in water distribution networks. *Water Resources Management 29*, 3459–3479. https://doi.org/10.1007/s11269-015-0966-2.

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