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Decision Support Model for Raw Water Availability for Purification in a Region in Chile

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Abstract

This article proposes a decision model to identify the most sustainable solution(s) to ensure the availability of raw water to be subsequently treated to be converted into drinking water as a consequence of the climate change scenario, particularly the drought currently experienced by the Metropolitan Region in Chile, derived from the technical and regulatory requirements associated with the availability of water resources from its capture to its drink ability to meet the future demand of the region. From the perspective of drought, the solution must provide security levels that guarantee the availability of raw water is one of the main concerns of the stakeholders. In turn, the need to adapt current regulations regarding raw water sources, as well as community acceptance of some proposals for converting raw water into potable water and climate dependency, involve qualitative as well as technical aspects that may affect the investment and operating costs of the different solutions required to ensure raw water availability.
Therefore, through a multi-criteria approach, it is possible to incorporate quantifiable and intangible aspects and to address conflicting objectives. Through a case study, we present a decision model based on the Analytic Hierarchy Process to define and evaluate the most sustainable solution(s) to secure raw water for drinking. This study proposes to integrate technical and qualitative attributes to identify the challenging criteria and the associated linkage to the problem of selecting proposals for the most sustainable solution(s) to secure raw water, being a guide to decide the implementation of the most appropriate solution.

Keywords: Decision support model, Raw Water, Potable, Climate Change, Multi-criteria Approach.

1 Introduction

In face of one of the worst droughts in history [1], it is not enough to increase water availability regardless of the cost. In Chile we have realized that there are some weaknesses in the use of the resource [2], in particular, because current irrigation technologies should be changed for more efficient ones (e.g., drip irrigation as in Israel); improve the efficiency of its use at the industrial level; reduce losses in drinking water distribution networks and reduce intra-household consumption.

With respect to the sanitary sector, the percentage of this resource that has not been allocated at the national level amounts to 32.9% of the volume produced [3]. There-fore it is essential to develop actions to reduce this indicator. It should be noted that the main items that constitute non-revenue water (NRW) are mainly physical losses in the network (due to breaks, leaks, etc.), but, also, include other items such as metering errors, clandestine connections, fraud and also non-revenue uses: washing of networks, fire fighting, etc. In recent years, as a result of climate change and increased demand, water scarcity has worsened [4] and competition for the reuse of treated wastewater and desalination has intensified [5].

However, in the Report on Water Resources Availability [6], Chile appears as a rich country. Indeed, the average per capita level is well above the world average. However, this index does not take into account the disparity of resources between the desert north and the rainy south, which is manifested in the fact that water scarcity has been a recurrent problem in the past, both in the north and in the center of our country [7]. This has meant that, historically, the available water has been reused, especially through the surface water distribution system, which divides each river into sections that receive the element in dry years, respectively.

On the other hand, at present, the urban sewerage coverage is 97.2% and, of this, practically 100% receives sewage treatment [3]. In other words, there is a relevant potential source consisting of about 300 operational treatment systems, which treat an average flow of about 40 m3/s. The most commonly used treatment technologies are: activated sludge (63%); aerated lagoons (18%) and submarine outfalls (11%). Once treated, most of the resource is discharged into different bodies of surface water, where it is mixed.

Strictly speaking, however, the additional flow available is much less, because not all treatment systems are located in areas of water scarcity. In the northern part of the country, a significant part is already being reused by mining.

In addition, in the central part of the country, which concentrates most of the population and demand, a large amount is being reused directly or indirectly for irrigation. It is also important to note that, due to water scarcity, the mining industry has adopted the use of treated wastewater for industrial processes and road irrigation. Likewise, the country has a great potential for desalination [8], however, it is noted that its costs are high, particularly if it is desired to supply areas far from the coast. However, in 2012, the Ministry of Public Works, in its National Water Resources Strategy 2012-2025 [6], identified desalination as: *"A safe source that guarantees stability of supply, given the variability of natural sources and the scarcity of the resource in the basins of the north of the country"*. In view of this, it is important to identify which of the alternatives for obtaining drinking water is more feasible to use in the medium term.

The research methodology is based on a case study, integrating planning processes, data analysis, scoring method interacting with the multi-criteria approach and using the Analytic Hierarchy Process (AHP) [9, 10, 11]. Therefore, this paper focuses on developing a decision model by identifying the levels and processes involved in the treatment of raw water to make it potable, collecting, managing and interpreting the available information.

A case study based on the current situation in the metropolitan region of Chile has been carried out to determine the most feasible process to be implemented in the medium term to ensure the availability of drinking water to the population. These results lead to the development of an investment plan that can be converted into action plans for the sanitary company in charge of drinking water supply. The following section provides a brief literature, review, Section 3 a description of the system, the following sections present the development of the model, its results and conclusions.

2 Literature Review

There have been some studies related to the water treatment system, in the literature is that of [16] Ramirez, Kraslawski, & Cisternas, who present an evaluation approach concerning the influence of energy consumption in the water system and its impact on the environment presenting a decision support framework. On the other hand, Herrera Sebastian et al [17], propose an optimization approach for the design of water supply systems in non-coastal areas with water scarcity. They determine the location and size of desalination plants and the design of the water conveyance net-work, including pipelines of specified length and diameter and pumping stations that minimize the capital and operating costs of the entire system. The document reported in [18], examines the water challenges facing the Latin America and Caribbean region in meeting the Sustainable Development Goal (SDG) of ensuring water availability, sustainable water management and sanitation for all. It uses the case of China as a context for analysis due to its particular performance and experiences in this area. This document specifically compiles the results of the technical discussion *"Challenges and opportunities for improving water management in Chile"*, from which the main messages and lessons learned are extracted for the formulation of recommendations, both for Chile and for other countries in the region.

3 System Description

The study refers to the development of a decision model. Since the people in charge of defining the medium-term planning of investments in water infrastructure want to know which infrastructure alternative would be the most feasible to develop in order to increase the resilience of the drinking water supply system, the criteria are not clear and there are different opinions that are expected to be agreed upon in order to generate the most viable alternative(s). However, the criteria are not clear and there are several opinions that are expected to be agreed upon in order to generate the most viable alternative(s).The system consisted of two stages. The first stage deals with the identification of the decisive factors and attributes to determine which criterion is most relevant at the time of making an investment in each of the solutions for obtaining raw water for potabilization. Empirical data were collected through inter-views, observation and a questionnaire containing open and semi-structured questions on the attributes most valued when defining the most appropriate infrastructure to meet the population's future demand for drinking water. As a result, numerous factors were raised and the critical effects were determined according to the valuation of the different benefits to be obtained. This practice made it possible to specify the criteria and structure the problem situation. Once the criteria and elements involved have been identified, the next step is to prioritize the different attributes by implementing a multi-criteria approach using AHP [12]. Subsequently, a comparison process is carried out.

The team of experts was made up of representatives of a sanitation company from the metropolitan region and representatives of the supervising agency, i.e., the Superintendence of Sanitation Services (SISS). The total number of participants from the sanitation company was 20 people, while from the supervising agency there were 10 people, ranging in age from 35 to 60 years old.

Once the criteria, factors and main representatives were established, a hierarchy structure was built. This incorporates the quantitative and qualitative variables and their relationships. The critical categories at each level were identified through the opinions issued by the Expert Panel. The multi-criteria approach allows conflicting objectives to be addressed through the use of AHP [13, 14, 15], which helps to establish criteria and rank user preferences.

4 Case study application methodology

The system under study is carried out in two parts. Initially, the concerns are to identify the decisive factors and attributes to define the hydraulic infrastructure required to ensure the supply of drinking water to the population in the medium term. Information is gathered from representatives of the Metropolitan Region's sanitation company and the regulatory body to define the main factors to be analyzed. Thus, many factors emerge and, therefore, it is necessary to identify the critical impacts. This practice makes it possible to state the criteria and structure the problem situation to generate a hierarchical structure to represent the problem situation and make an assessment. The next step is to prioritize the different attributes through a peer comparison process. One team of experts is formed by representatives of the health company and another by the regulatory agency. The AHP method is used to rank and evaluate the different factors and elements considered in the hierarchy. The experts' judgment is based on their own experience and knowledge. The last step is to record the weighting of the measured attributes of each activity to obtain a rating on the water infrastructure that will increase the safety of drinking water supply.

4.1 Structuring the AHP hierarchy model

The hierarchy structure model is shown in Figure 1. The general objective is indicated at the first level, in reference to the water infrastructure required to support the entire current drinking water supply system in the medium term. The next level refers to the relevant criteria that will allow defining, according to the second level, the technology to meet the general objective.

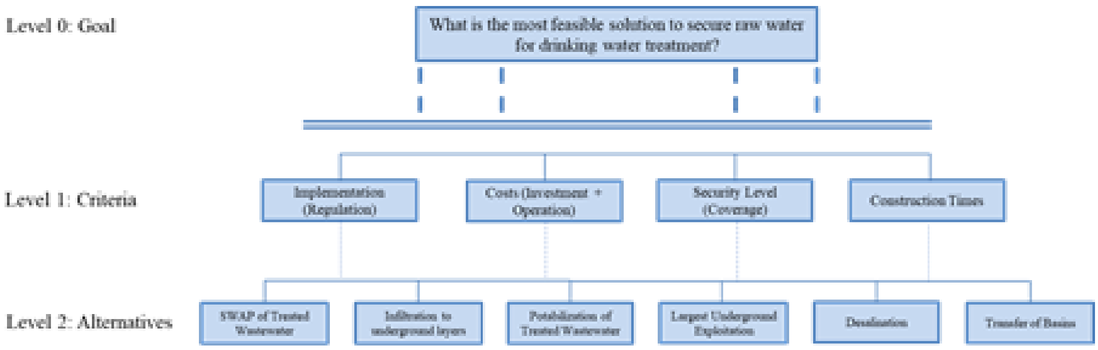

Figure 1: Primary hierarchy model.

4.2 Pairwise evaluation

A first results for a overall relative prioritization for criteria, level 1 and technology are shown in Figure 2.

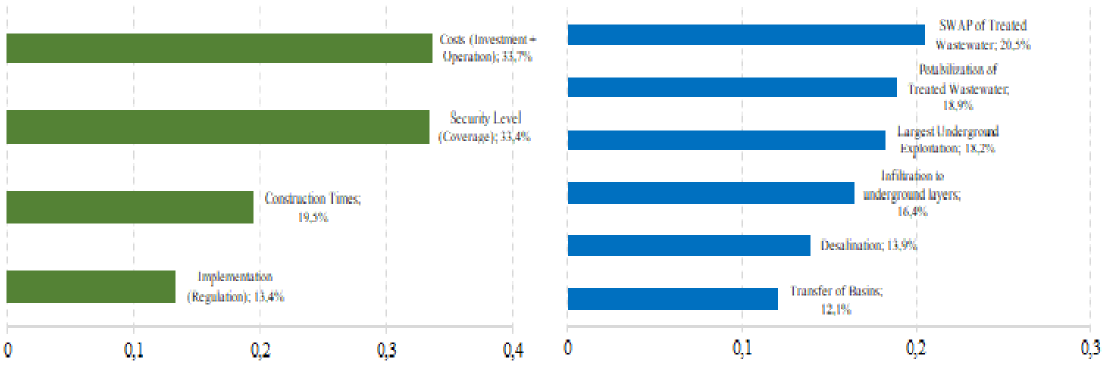

Figure 2: Primary hierarchy model.

The team of experts made up of the two types of representatives went through an evaluation process, along the hierarchy based on their judgment of the allocation made for the current situation. From this overall result, the Wastewater Reuse SWAP and Treated Wastewater Potabilization are more important for all participants, with a priority of 20.5% and 18.9% respectively. Now, if we consider the importance between the Wastewater Reuse SWAP and the Treated Wastewater Purification SWAP, as shown in Figure 3, the group of experts considers that the Wastewater Reuse SWAP is more relevant because it has lower costs and the execution times are shorter, which allows having water security in a shorter period of time.

Figure 4 shows the comparison between the Wastewater Reuse SWAP and Increased Underground Exploitation (Wells), with the Wastewater Reuse SWAP being more relevant because it provides greater coverage of raw water treatment, thus increasing the exploitation of wells, given the sustained decline in groundwater

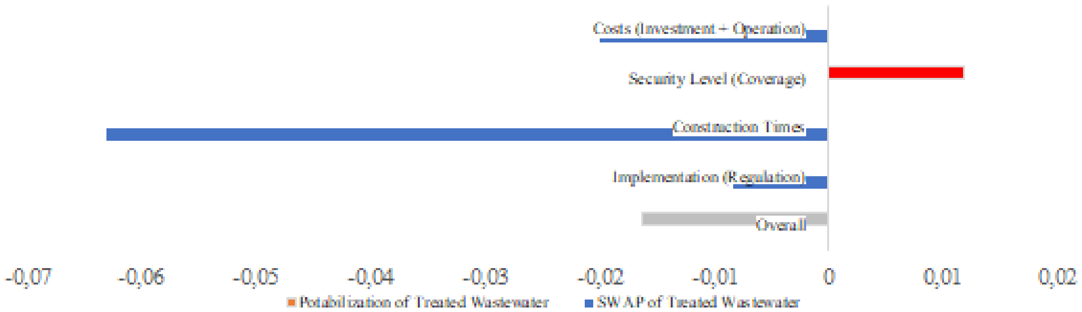

Figure 3: SWAP of Treated Wastewater vs. Potabilization of Treated Wastewater.

Figure 4: SWAP of Treated Wastewater vs. Largest Underground Exploitation.

5 Result analysis

By using the AHP methodology [9, 10] and data processing through the Expert ChoiceTM (EC) software[11], a relative order was acquired. The priority results showed that the Costs (Investment and Operation) is a determining factor when deciding which hydraulic infrastructure to consider to ensure drinking water supply in the Metropolitan Region. This result is consistent with the preliminary vision of the sanitation company and the regulatory body to propose future action plans to adapt to climate change, ensuring the continuity of drinking water service in a timely manner and thus avoid affecting customers and impacting the city. These results are consistent with the policy of studying alternatives for reusing wastewater and thus generating a virtuous circle, known as the circular economy, given that much of the water consumed can be recovered. However, a preliminary issue to generate these investments is to educate the population about this new alternative to obtain drinking water, since there is no knowledge and there is disbelief regarding the use of wastewater as an initial source for the generation of drinking water. The first column of Table 1 shows the overall results of the technology where it is recommended to invest in projects associated with the SWAP of treated wastewater.

Table 1: Local and Global priority results

		Local Priorization					
Criteria / Alternatives	Criteria Global	SWAP of Treated Wastewater	Infiltration to underground layers	Potabilization of Treated Wastewater	Largest Underground Exploitation	Desalination	Transfer of Basins
Costs (Investment + Operation)	**0,337**	0,181	0,209	0,160	0,237	0,109	0,104
Security Level (Coverage)	0,334	**0,287**	0,035	**0,299**	0,047	**0,173**	**0,159**
Construction Times	0,195	0,211	0,244	0,148	0,222	0,109	0,066
Implementation (Regulation)	0,134	0,054	**0,259**	0,046	**0,320**	0,172	0,148
Global Importance		**0,205**	**0,164**	**0,189**	**0,182**	**0,139**	**0,121**

Based on the results, it should be noted that the relevance assigned to operating costs (investment and operation) would depend on the country and/or region in which it is evaluated, depending on the availability of water and future projections of its impact, due to the change in clients. Current investments in water infrastructure are generally highly complex, and the industry has historically generated infrastructure to use available water from rivers and groundwater, since there was no need to look for alternative sources, which is no longer feasible, due to water scarcity in Chile. The AHP allows to perform sensitivity analysis, allowing to identify possible changes in the ordering processes, modifying the importance of the criteria. The relevance of the analysis lies in the current water situation in the country, the regulations in force and the knowledge of the available technologies for the generation of raw water for drinking water. Figure 5 shows a sensitivity analysis that allows visualizing, depending on the assessment made by the group of experts at a future opportunity, the feasible infrastructure may be different depending on the relative weight resulting from these criteria, considering the previous analysis. The results of the model show alignment with the sanitary policies currently being envisioned by the industry to increase the availability of raw water.

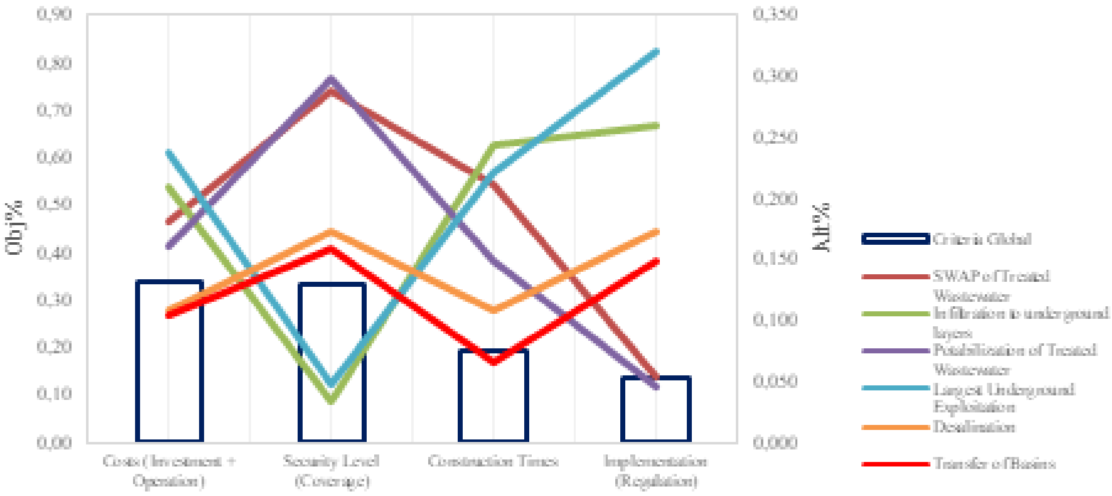

Figure 5: Sensitivity analysis for factor "performance"

6 Conclusions

This paper proposes a methodology using a multi-criteria approach using AHP to develop a decision model based on a real case study. The use of the AHP model helps to improve the understanding of technology needs and the selection process in a conflicting environment. The ranking obtained not only helps to initiate implementation actions but also to generate an investment plan. It allows recognizing the critical factors that influence the decision to choose the hydraulic infrastructure that will help improve the quality of service and adapt to changes in sanitation needs. The challenges facing the sanitation system in developing countries include technology, infrastructure, cost efficiency and water resource sustainability.

Regarding the solution obtained through AHP, there is consistency considering that in the north of the country, industries such as mining and specific irrigation programs are promoting the reuse of treated wastewater.

Also, the SISS is currently studying specific regulations on the reuse of treated wastewater. In addition, it has become an essential part of integrated water resource planning and management, both in developed and developing countries, since the problem of water scarcity is not only in Chile, but there are several countries in the same situation, where they are also facing an increase in population and demand for food and concern about environmental pollution.

However, as shown by the results for the case of SWAP of Wastewater Reuse and Potabilization of Treated Wastewater, it entails changes in the traditional structures of water resources allocation, financing of structures, consideration of water quality standards that should be approved by the SISS and encourage the use of these alter-natives by subsidizing their investment so that they are adopted as soon as possible.

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