AN INTEGRATED MODEL APPROACH FOR DISASTER IMPACT REDUCTION: LESSONS FROM A SLOW ONSET DISASTER IN CHILE

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ABSTRACT: Purpose – The prolonged drought in Chile's Coquimbo region has created a permanent state of emergency, forcing the state to spend millions each year distributing drinking water to rural communities. The purpose of this article is to detail a study focused on optimizing the supply of drinking water through trucks in the 15 communes of the region and how the problem was faced in a context of a slowonset disaster. Design/methodology/approach – A geo-referenced census and optimization analysis of the 5.541 households that receive drinking water was conducted to determine the feasibility of removing trucks from the system. To generate a greater reduction in distribution costs, it was suggested to incorporate water distribution infrastructure projects, changing the concept of 'expenses' to 'investment'. Findings – The study was born out of the concern for the increased demand for drinking water from rural areas. The proposed and implemented framework allowed an additional 20% reduction in the initial transportation costs; this confirmed the assumption that the proposed optimization model alone would not offer a robust solution and was complemented and integrated with this type of alternative, forming an "integrated model". Research limitations/ implications – The paper has implications for the resilience of territories affected by climate change. Practical implications – The methodology can be replicated in other areas where similar interactions occur. Social implications – Families impacted by drought can improve their quality of life and reduce distress in the face of the constant emergency. Originality/value – This research aims to contribute knowledge from the perspective of a slow-onset disaster where water resources are scarce. It presents a

framework where two disciplines converge, resulting in an "integrated model" that, through its implementation, reduces the costs of resource delivery while simultaneously improving the sanitary conditions of the beneficiary families.

KEYWORDS: Slow-onset disaster, Drought, Drinking water, Trucks, Resilience, Humanitarian logistic

INTRODUCTION

The Global Assessment Report on Disaster Risk Reduction by the United Nations Office for Risk Reduction (UNDRR, 2022) reveals that over the past two decades, an average of 350–500 disasters of varying types and scales have occurred annually, with a projected increase to 560 per year by 2030. Notably, the economic impact of these disasters disproportionately affects developing countries, accounting for approximately 1% of their global gross domestic product, while in developed countries, the impact is less than 0.3%. As highlighted by Thomas and Kopczak (2005), this trend demonstrates a concerningacceleration in the effects of disasters across different regions globally. UNDRR (2022) emphasizes that the escalating frequency of disasters poses a significant obstacle to the achievement of the sustainable development goals (SDGs), attributing this challenge to insufficient collaborative efforts in bolstering resilience and mitigating systemic risks, as elaborated by Sillmann *et al.* (2022).

In terms of disaster taxonomy, Van Wassenhove (2006) proposed a bifurcation of natural disasters into two primary categories: slow-onset disasters (e.g. famines, droughts) and sudden disasters (e.g. earthquakes, hurricanes). Slow-onset disasters are characterized by a gradual onset, as articulated by Mishra and Sharma (2020). The conventional use of the term "natural" in conjunction with disasters has spurred debate within academic and professional circles (Kelman *et al.*, 2016; UNDRR, 2020), challenging the notion of disasters as purely natural phenomena.

Staupe-Delgado (2019) notes that managing slow-onset disasters presents multifaceted challenges that diverge from traditional disaster management paradigms. Cole *et al.* (2021) underscored that effective disaster preparedness necessitates a blend of interdisciplinary competencies, integrated data systems, scenario-based simulations and the application of domain-specific expertise. However, as Bahinipati and Gupta (2022) highlighted, documented indicators for loss and damage (L&D) associated with slow-onset disasters still need to be developed.

Key factors implicated in slow-onset disasters encompass real-time data collection and exchange, adequate provisioning of essential resources, addressing transportation bottlenecks and accurately identifying initial relief requirements. Scholars such as Scissa and Martin (2024), Baporikar and Shangheta (2018) and Besiou and Van Wassenhove (2020) advocate for renewed attention toward addressing slow-onset disasters. Kunz and Reiner (2012) advocate for enhanced logistical considerations in ongoing relief efforts in response to protracted human-induced disasters. Supporting this, Staupe- Delgado (2019) points out that gradual threats often go overlooked, allowing their impacts to accumulate until they reach critical levels, even in cases with advanced warning systems. Understanding the underlying reasons for the lack of proactive responses to such phenomena is essential, underlining its significance in achieving the objectives outlined in the Sendai Framework for Disaster Risk Reduction (SFDRR).

In the field of humanitarian logistics, scholars have reported the limited theoretical development and empirical studies related to so-called slow-onset disasters, compared to the greater number of studies on sudden-onset disasters (Leiras *et al.*, 2014; Tatham and Christopher, 2018; Jiang and Yuan, 2019; Anjomshoae *et al.*, 2022; Malhouni and Mabrouki, 2023). Staupe-Delgado and Rubin (2022) argue that the failure to recognize the impacts of progressive disasters as a distinct type of social problem has led to insufficient theorization and underestimation of their particular challenges in disaster risk science. Therefore, case study methodologies have been required to develop research on humanitarian logistics (Kunz and Reiner, 2012).

The Coquimbo Region in Chile has experienced climatic changes that have led to its declaration as an arid zone, bringing various issues that have accumulated for more than ten years. One of these issues relates to providing potable water for human consumption within its three provinces, especially in rural areas that lack a standard distribution network like the urban concessioned areas. The rural population, where the drought impact is most concentrated, is in more isolated situations. It needs a rural potable water system and only has precarious individual wells or relies on highly vulnerable sources, such as small water springs that have entirely dried up. The Coquimbo Region covers an area of 40,574 km^2 and is structured into three provinces: Elqui, Limarí and Choapa. It is further divided into 15 communes: Andacollo, Coquimbo, La Higuera, La Serena, Paihuano, Vicuña, Combarbalá, Monte Patria, Ovalle, Punitaqui, Río Hurtado, Canela, Illapel, Los Vilos and Salamanca. In this context, the authorities of the Regional Government expressed their concern about the growing demand for potable water for consumption and the significant cost it entails for the State. With this background, the challenge was posed to seek solutions to support and help mitigate this issue and try to improve the quality of life of our rural population.

In Chile, potable water supply is provided by sanitation companies [1] (in "concessioned" urban areas) and rural potable water systems (RPW) [2]. Rural families without regular supply are served by water tanker trucks. According to data from the Ministry of the Interior and Public Security (2020), more than 500,000 citizens had to obtain water through trucks paid for by the Government and Municipalities, resulting in an accumulated public expenditure over the past five years exceeding US$192m. Together, these studies merely indicate a reality that is becoming increasingly common and needs to be studied; in addition, they highlight the need to build comprehensive frameworks, timely interventions and better protective measures to manage slow-onset disasters effectively.

In response to the above, the present research focuses on the problem caused by drought as a slow-onset disaster and the challenge of delivering water for human consumption. Specifically, the research arose due to the sustained increase in demand for potable water in rural areas indicated by the Regional Government of Coquimbo (GORE), Chile. The objective set by the GORE was to explore solutions to reduce the cost of transporting the resource by trucks, all within water scarcity. Through the execution of two projects funded by the Regional Competitiveness Innovation Fund (FIC-R) between 2015 and 2019, two empirical studies were generated: the first study aimed to develop a model to optimize potable water transportation and thus reduce transportation costs. The second study aimed to develop and implement infrastructure projects (IPs) as long-term support (thus forming an "integrated model"). This latter stage also sought to answer how the system could adapt to environmental shocks and continue functioning (Manyena, 2006).

Although globally, droughts represent only 3% of the total number of disasters and 3% of deaths, they account for 35% of the total number of people affected in disaster situations (CRED, 2020). Notably, the human right to drinking water was first recognized by the UN General Assembly and the Human Rights Council as part of binding international law (UN, 2010). However, it is likely that climate change will cause an increase in aridity, reduced runoff and a decrease in water supply for cities worldwide (Murray *et al.*, 2012). Similarly, the UN General Assembly explicitly recognized the human right to sanitation as a distinct right (UN, 2016). The lack of access to safe, sufficient, and affordable water, sanitation and hygiene facilities has a devastating effect on billions of people's health, dignity and prosperity. It has significant consequences for realizing other human rights (UN-Water, 2020). The World Health Organization recognizes drinking water supply through trucks or haulage as an alternative in emergencies. In this regard, UN-Water (2020) states that the costs of generating "nonconventional" water resources (including transport by trucks) can be considered high, but in the face of disease risks produced by interaction with other distribution systems, it should be considered as an alternative and its monetary cost evaluated. The supply of drinking water by trucks is a global situation (Chirinos *et al.*, 2004; Gómez and Palerm, 2015; WaterCanada, 2017; EcoWatch, 2018; De Las *et al.*, 2018), indicating the existence of problems that have persisted over time.

This work has several contributions. First, unlike many studies that focus on sudden disasters, this article focuses on slow-evolving disasters such as droughts, following the line of research proposed by Staupe-Delgado (2019). Although optimizing delivery routes for humanitarian logistics is not entirely new (Pérez-Rodríguez and Holguín-Veras, 2016; Bahinipati and Gupta, 2022), its application to a permanent state of emergency presents a novel approach. Second, the long-term planning and efficiency improvements approach provides a new paradigm for reactive emergency response. This research incorporates long-term IPs. Finally, the third contribution is that it uses a census methodology that offers several advantages over a sampling methodology. Collecting information from every unit in the population avoids any selection bias that might arise in a sampling methodology, resulting in greater precision and allowing for microlevel analysis.

The article is structured as follows: Section 2 presents the methodology for addressing the water distribution issue. Section 3 shows the study's results and discussion. Finally, we conclude the article in Section 4.

METHODOLOGY

Problem description

First, to achieve the research objective, it was proposed that a qualitative and quantitative diagnosis of the demand/supply situation for rural drinking water in critical areas on a regional scale be developed due to the lack of a unified territorial information system. To define the optimization model for water distribution, meetings were held with representatives from the Regional Government, the mayors of the 15 municipalities, their emergency unit heads and the beneficiaries. A model was proposed whose function allowed iterating the number of trips made by a truck i to a route j on day k to determine the number of trips that minimizes the total number of trips. In humanitarian logistics, different mathematical optimization models have been used (Kovács and Moshtari, 2019; Hezam and Nayeem, 2021). For this case, the model studied by Castillo-Vergara *et al.* (2014) was used as a basis, limiting the daily operating hours to 9 h. It is important to mention that there are models (Pérez- Rodríguez and Holguín-Veras, 2016) that incorporate deprivation costs; however, in this model, it was defined that water distribution would occur five days a week to maintain quality and ensure beneficiaries' confidence in resource availability. Such an approach could be seen as a buffer against the stress of depending on daily distribution; this highlights the type of decisions made in the specific context of a slow-onset disaster.

Regarding the constraints, these are primarily expressed in the drivers' working hours and days, the water demand of each route, the daily availability of water from the supply source and the number and capacity of the trucks contracted in each of the municipalities involved in the project. Table 1 shows the variables and parameters included in the model. The model is defined as follows:

$$\mathrm{Min} \sum_{i=1}^{n} \sum_{j=1}^{m} \sum_{k=1}^{z} x_{ijk}$$

$$\sum_{i=1}^{n} \sum_{k=1}^{z} \mathrm{cap_i} * x_{ijk} \quad \geq \mathrm{d_j} \quad \forall \quad \mathrm{j}$$

$$\sum_{i=1}^{n} \sum_{j=1}^{m} \mathrm{cap_i} * x_{ijk} \quad \geq \mathrm{o_k} \quad \forall \quad \mathrm{k}$$

$$\sum_{j=1}^{m} \mathrm{t_{ij}} * x_{ijk} \quad \leq h \quad \forall \; i, k$$

$$x_{ijk} \quad \geq 0 \qquad Integer$$

As a socio-technical study (Holguín Veras *et al.*, 2012) on optimizing rural drinking water distribution, an analysis specific to the field of operations research was applied while considering the conditions of the territory and the beneficiary families. To identify the beneficiaries and reduce epistemic uncertainty, a baseline survey was planned through a geo-referenced regional census, including the 5,519 homes benefiting from the drinking water distribution, constituting the total population. The unit of analysis was the Coquimbo Region, with data selection conducted at the communal level, disaggregated into its three provinces (Elqui, Limarí and Choapa) and 15 communes. The data collection units corresponded to the localities and their beneficiaries.

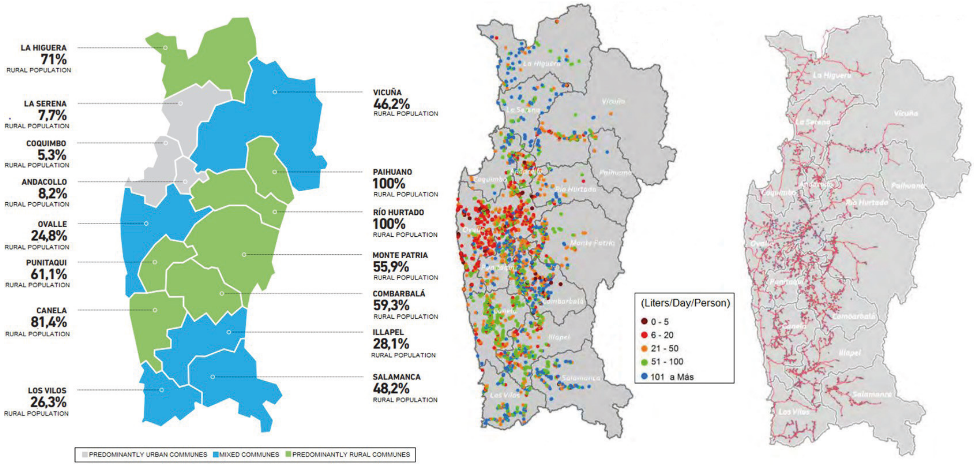
Variable/ parameter	Description	Notation
Decision variable	Number of trips by truck i to route j on day of week k	x_{ijk}
Travel time	Total time from the supply point to the delivery point in a truck type i on route j, includes round trip travel time. A distance-weighted average speed is used to determine this time	t_{ij}
Truck capacity	Capacity of each truck in liters, quantities obtained from records of each commune	cap_i
Route demand	Total demand for route j based on 50 liters/person/day; adjusted based on the parameters of minimum standard of response to a disaster, equivalent parameters defined by WHO, and the minimum indicated by UN	d_j
Amount of water available	Liters of water available per day per load point	o_k
Maximum daily operation time	Daily operation time of each truck, set at 9 h, based on effective working hours obtained from field data	h

Table 1 Variables and parameters of the optimization model

Source: Created by the authors

Data modeling and optimization

The data collection period took place from February 2015 to March 2016. Field data were recorded on four forms: loading point (loading point of the trucks, truck equipment, source recharge time, m^3 of water available per day, owner), unloading point (supply frequency, storage capacity, water uses, inhabitants per dwelling, liters delivered, material and condition of storage elements, distance from the dwelling to the storage elements), truck (truck license plate, capacity in m^3, equipment, year, operating routes, work schedules, work days, route time) and route (type of road, technical conditions of the road, accessibility, speeds, length, assigned dwellings). The results were consolidated into a geo-referenced database (with 38 variables for each beneficiary) and transferred to a Geographic Information System (GIS). This census methodology provides a complete and accurate picture of the current situation, providing a solid foundation for informed decision-making and resource optimization. By having a comprehensive view of demand and supply, it is possible to optimize distribution routes and reduce operational costs. This approach has been supported by recent research highlighting the importance of comprehensive data for logistics optimization in humanitarian operations (Kovács and Moshtari, 2019). Appendix 1 shows the forms used in the census. Figure 1 shows the result with the geo-referenced points and transport routes in the GIS.



Source: Created by the authors

Figure 1 Georeferenced baseline data

To coordinate operations, information about the study was shared with the 15 municipalities in the region, who committed to supporting the data collection. An important element of our work was encountering high variability in transport operations, as each municipality used different control tools, which can complicate the collection. The team assembled for data capture consisted of 12 people, divided into three field operational teams. Teams A and B addressed one municipality at a time until they recorded 100% of the data. For team C, the approach was different. This team conducted a rapid tour through the municipalities in the region with the objectives of coordinating with the potable water distribution managers of each municipality to initiate the recording of the points to be surveyed and characterizing the sector before the census with logistical information, distribution schedules, loading point locations and conducting user surveys. This team was responsible for systematizing the information to inform the other groups. To avoid nonresponse bias, the field teams visited the households multiple times, achieving a nonresponse rate of less than 2% of the total. A summary of the information disaggregated by province is shown in Table 2.

Province	Loading points	Unloading points	People benefited	Total locations	No. of trucks	No. of liters delivered per month
Elqui	7	768	3774	199	18	5092530
Limarí	7	2916	15850	444	39	11743510
Choapa	7	1835	8349	173	26	6756260
Total	21	5,519	27,973	816	83	23592300

Table 2 Summary of total rural potable water distribution, Coquimbo Region

Source: Created by the authors

Once the regional database was obtained, the origin-destination matrix was developed, including information on routes, vehicles, water demand, supply and the weekly schedule. The following tools were used to obtain the model solution: Genetic Algorithm (GA), OptQuest and DecisionTools Suite 7.6 Industrial; GA encodes each possible solution to the problem in the form of a "chromosome" (a data string that contains all the values of the decision variable). The algorithm begins by generating an initial population of possible solutions randomly within the binary value space of the origin-destination matrix in Figure 2. Each solution is evaluated using a "fitness function," assessing how well it performs in terms of the objective function, and the most "fit" solutions are selected to reproduce and generate the next generation of solutions. To prevent the algorithm from getting stuck in a local optimum, a random mutation is introduced in some chromosomes, which may lead to the exploration of new areas in the solution space. The algorithm halts when it finds the solution that achieves the best performance while meeting the constraints and the objective function. Fifteen solution models were generated, one for each of the municipalities.

Model redesign: incorporation of infrastructure investments

In the field, limitations of the model were observed, mainly influenced by the variability of transportation operations, demand and data updates. The primary issue was that each municipality used a different control tool for truck distribution and internal administrative processes. This complicates monthly control at the central level, as there was no information on the m^3 loaded and distributed. In addition, delivery route assignments were often made at the last minute, impacting proper planning and process costs. With this background, the objective shifted from merely minimizing costs to propitiate the beneficiary group's resilience. It was proposed that IPs for water distribution be incorporated as a complement to the optimization model to replace operational costs with investments. IP refers to designing a water distribution network (pipelines) with an accumulation tank (where the source is the truck that supplies water). These designs fulfill the primary function of grouping many beneficiaries (drinking water recipients) who share certain characteristics, mainly the number of unloading points (households), their proximity to each other and the water delivery route they are on (longer routes are preferable). For example, the number of beneficiaries determines the unloading time at each point; in addition, the length and characteristics of a route (km) determine the travel time. Figure 3 shows the plan of an IP.

The technical condition for proposing the IPs was based on reducing the time spent by trucks emptying water at a common source compared to distributing it house by house, thereby reducing travel, route and truck times. Field data indicate that the average emptying time was 20 min per house. If a group of 10 houses is considered, it requires 200 min of emptying time. On average, the emptying time of a 10 m^3 tank was 45–50 min (unloading into a tank represents a time reduction of approximately 80%). In designing a PI, gravity propulsion was prioritized to avoid energy costs for pumping; in addition, a solar-powered water recirculation system was considered for the tanks. A summary of the study design (framework) is presented in Figure 4.

RESULTS AND DISCUSSION

An integrated optimization model with IP was generated for each of the 15 municipalities in the Coquimbo Region. Given the extensive nature of the results from both the optimization model and the subsequent integration with the IP, this work presents the results for one of the municipalities analyzed. Monte Patria in the Province of Limarí was selected as an example of the model's execution because it provides more information for understanding the integrated model and is also where the most significant investment and implementation of IPs occurred.

The first step was to create a matrix with information on the water distribution routes in the municipality of Monte Patria. The data were extracted from the GIS obtained during the census stage. Appendix 2 shows the resulting matrix. Table 3 presents the disaggregated summary of the potable water distribution by trucks in the Coquimbo Region.

In Figure 2, the origin-destination matrix resulting from the application of the linear optimization model is shown. In this case, the results indicate that optimization can reduce four trucks. The weekly schedule would be set four days a week (Monday to Thursday), leaving Friday without assigned vehicles. However, the regional authority decided to only eliminate trucks 4 and 7, justifying their decision based on prudence regarding the variability in demand at that time, even though the model suggested eliminating trucks 4, 7, 10 and 11. Table 4 shows the result of applying the optimization. The 32% slack over the direct demand for potable water represents the additional response capacity for future variations.

Table 5 presents the distribution cost estimation. Column (1) highlights the costs of the trucks that were removed from service, generating a monthly saving of US$10,985 (approximately 18%). Column (5) shows the cost variation produced by the model, resulting in a total saving of approximately 23%.

Table 6 shows the implemented IPs, the investment amounts, the number of trucks that could be reduced in the municipality and the projected expense reduction considering an infrastructure lifespan of three years. The execution of the integrated model (optimization model 1 IPs) establishes the nonuse of four trucks in the Monte Patria Municipality, amounting to US$270,796 annually and a direct investment in network infrastructure of US $129,910, benefiting 40 families and a total of 170 people. It is important to mention that approximately 8% of the total homes lacked adequate storage elements, and 28% were in poor or regular condition. Beyond the correct and timely delivery of potable water, the suitability of the storage elements was critical to ensure water quality over time; optimization becomes futile if people do not have the minimum conditions. A flow control mechanism was recommended at the truck outlets to control the delivery, and it also became necessary to have a global positioning system in the vehicles.

Well Capacity (lts/day) 300.000 Hours/Day= 9

MONTE PATRIA — Trips to be Taken (#)

	TRUCK CAP. LTS.	DAY	TRUCK	ROUTE 1	ROUTE 2	ROUTE 3	ROUTE 4	ROUTE 5	ROUTE 6	ROUTE 7	ROUTE 8	ROUTE 9	ROUTE 10	ROUTE 11	ROUTE 12	ROUTE 13	ROUTE 14	ROUTE 15	ROUTE 16	ROUTE 17	ROUTE 18	ROUTE 19	ROUTE 20	ROUTE 21	ROUTE 22	ROUTE 23	ROUTE 24	ROUTE 25	ROUTE 26	ROUTE 27	ROUTE 28	ROUTE 29	ROUTE 30	Offer	Maximum Operating Hrs/Day
1	11.000	MONDAY	Truck 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	154.000	5,7
2	11.000		Truck 2	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		6,0
3	5.000		Truck 3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1		8,1
4	15.000		Truck 4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0,0
5	10.000		Truck 5	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		8,0
6	11.000		Truck 6	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		8,0
7	20.000		Truck 7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0,0
8	15.000		Truck 8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0		7,2
9	10.000		Truck 9	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		6,4
10	10.000		Truck 10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0,0
11	16.000		Truck 11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0,0
12	10.000		Truck 12	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		8,2
1	11.000	TUESDAY	Truck 1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	142.000	8,6
2	11.000		Truck 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0		8,6
3	5.000		Truck 3	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		8,6
4	15.000		Truck 4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0,0
5	10.000		Truck 5	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		8,0
6	11.000		Truck 6	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		5,8
7	20.000		Truck 7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0,0
8	15.000		Truck 8	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		5,9
9	10.000		Truck 9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		8,6
10	10.000		Truck 10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0,0
11	16.000		Truck 11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0,0
12	10.000		Truck 12	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		8,3
1	11.000	WEDNESDAY	Truck 1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	176.000	8,3
2	11.000		Truck 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0		8,6
3	5.000		Truck 3	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		8,6
4	15.000		Truck 4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0,0
5	10.000		Truck 5	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		5,6
6	11.000		Truck 6	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		6,4
7	20.000		Truck 7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0,0
8	15.000		Truck 8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0		3,8
9	10.000		Truck 9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		8,6
10	10.000		Truck 10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0,0
11	16.000		Truck 11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0,0
12	10.000		Truck 12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0		5,9
1	11.000	THURSDAY	Truck 1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	227.000	7,0
2	11.000		Truck 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0		5,5
3	5.000		Truck 3	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		7,2
4	15.000		Truck 4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0,0
5	10.000		Truck 5	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0		5,8
6	11.000		Truck 6	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0		8,5
7	20.000		Truck 7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0,0
8	15.000		Truck 8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0		3,8
9	10.000		Truck 9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0		5,9
10	10.000		Truck 10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0,0
11	16.000		Truck 11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0,0
12	10.000		Truck 12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0		8,7
1	11.000	FRIDAY	Truck 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	225.000	0,0
2	11.000		Truck 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0,0
3	5.000		Truck 3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0,0
4	15.000		Truck 4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0,0
5	10.000		Truck 5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0,0
6	11.000		Truck 6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0,0
7	20.000		Truck 7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0,0
8	15.000		Truck 8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0,0
9	10.000		Truck 9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0,0
10	10.000		Truck 10	0	0	0	0	0	g	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0,0
11	16.000		Truck 11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0,0
12	10.000		Truck 12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0,0
			Dem.	1.810	2.940	8.530	7.220	21.000	5.930	4.840	5.380	7.400	3.150	9.120	6.400	4. 600	4.800	8.290	880	3.830	5.970	6.310	10.800	7.640	8.410	9.560	8.230	9.710	7 960	7.510	9.730	9.580	4.460		
			Δ Lts.	8.190	18.060	22.470	3.780	0	5.070	160	4.620	3.600	17.850	5.880	3.600	38.400	10.200	11.710	9.120	1.170	5.030	8.690	14.200	3.360	2.590	5.440	1.770	1.290	3.040	2.490	5.270	1.420	540		

Tiempo x Viaje (Horas/Viaje)

	TRUCK	ROUTE 1	ROUTE 2	ROUTE 3	ROUTE 4	ROUTE 5	ROUTE 6	ROUTE 7	ROUTE 8	ROUTE 9	ROUTE 10	ROUTE 11	ROUTE 12	ROUTE 13	ROUTE 14	ROUTE 15	ROUTE 16	ROUTE 17	ROUTE 18	ROUTE 19	ROUTE 20	ROUTE 21	ROUTE 22	ROUTE 23	ROUTE 24	ROUTE 25	ROUTE 26	ROUTE 27	ROUTE 28	ROUTE 29	ROUTE 30
1	TRUCK 1 TO TRUCK 12 (TRAVEL TIME/ROUTE)	3,05	8,62	8,00	5,75	6,42	4,22	7,18	2,50	1,75	8,30	3,82	8,20	2,00	2,05	8,60	8,70	5,25	8,55	7,20	3,80	4,25	5,50	1,47	5,92	4,75	5,25	5,92	2,35	3,82	2,88

Figure 2 Source-destination matrix resulting from the optimization of potable water distribution, Monte Patria municipality

Source: Created by the authors

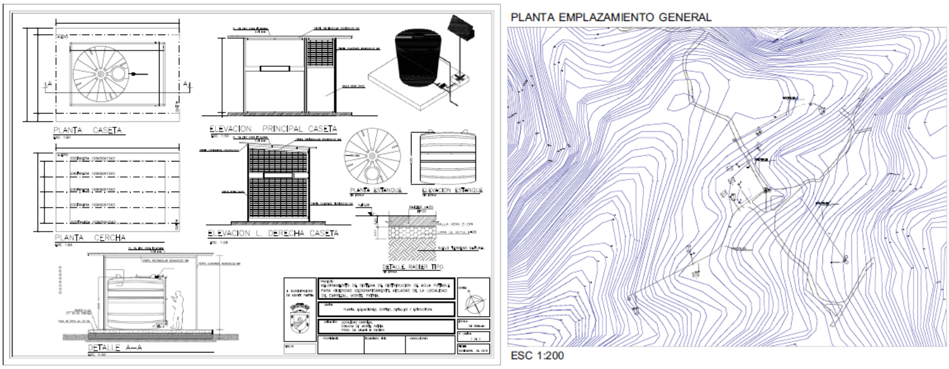


Figure 3 Main plan of the infrastructure project for the storage and distribution of potable water for human consumption

Source: Created by the authors

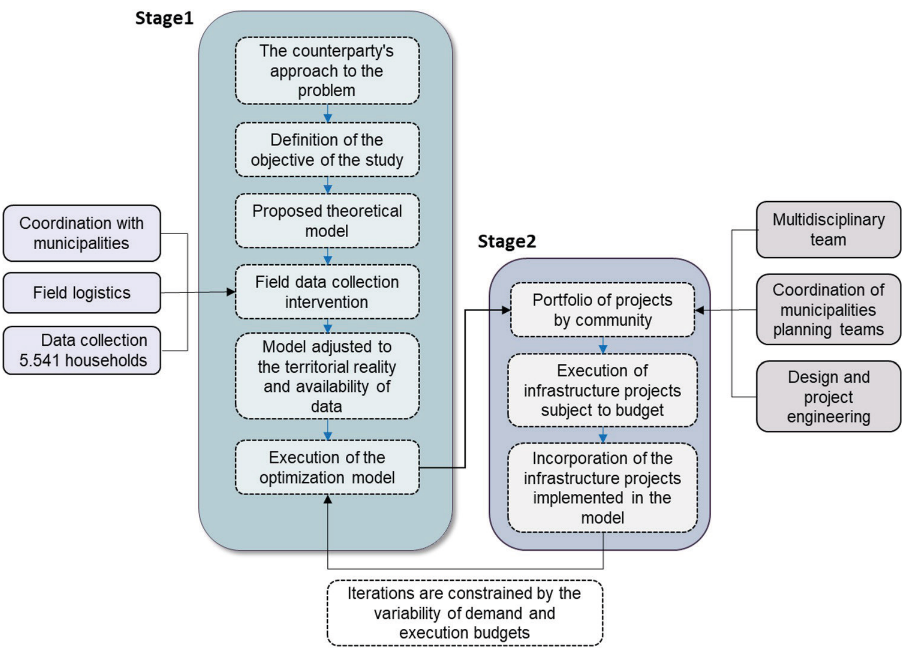


Figure 4 Proposed_framework

Source: Created by the autors

Province	Municipality	# Trips/ week	(1) # Benefi-ciaries	(2) Demand liters / week	(3) Capacity delivery liters	(4) = (3) – (2) Offer — demand
Elqui	La Higuera	18	500	105000	180000	75000
	Paihuano	18	77	18865	20000	1135
	La Serena	20	350	73500	150000	76500
	Coquimbo	35	603	126630	245000	118370
	Vicuña	20	593	103775	200000	96225
	Andacollo	42	1,268	318500	365000	46500
Limarí	Ovalle	170	4,174	876540	1242000	365460

	Rio Hurtado	12	351	73710	120000	46290
	Monte Patria	54	2,222	389000	574000	185000
	Combarbalá	80	3,821	638950	897000	258050
	Punitaqui	89	3,690	623620	912000	288380
Choapa	Illapel	66	1,877	394170	597000	202830
	Salamanca	48	2,674	355740	620000	264260
	Canela	61	1,913	401730	566000	164270
	Los Vilos	54	1,732	363720	597000	233280
	Totales	787	25,845	4863450	7285000	2421550

Table 3 Disaggregated summary of water distribution, Coquimbo Region

Source: Created by the authors

Truck	# trips/week	(1) # Beneficiaries	(2) Demand liters / week	(3) Capacity delivery liters	(4) D Offer/ demand
Truck 1	8	2222	389000	88000	32%
Truck 2	6			66000	(3–2)
Truck 3	4			20000	
Truck 4	—			—	
Truck 5	5			50000	
Truck 6	5			55000	
Truck 7	—			—	
Truck 8	5			80000	
Truck 9	5			50000	
Truck 10	6			60000	
Truck 11	5			50000	
Truck 12	5			50000	
TOTAL	54	2222	389000	574000	185000

Table 4 Summary of rural potable water distribution, Monte Patria

Source: Created by the authors

Actual				Proposed (with model applied)	
	(1)	(2)	(3)	(4)	(5)
Truck	Monthly service costs US$ without model	km, traveled/month with model applied	US$/ km	Monthly service cost with applied model US$	D US$ (4) – (1)
Truck 1	6,229	2080	3	6,411	182
Truck 2	4,043	1220	3	3,760	—282
Truck 3	4,260	1464	3	4,512	253
Truck 4	4,768	—	—	—	—
Truck 5	5,141	740	3	2,281	—2,860
Truck 6	5,074	780	3	2,404	—2,670
Truck 7	5,702	—	—	—	—
Truck 8	5,685	1344	3	4,143	—1,543
Truck 9	5,702	1280	3	3,945	—1,757
Truck 10	4,469	960	3	2,959	—1,510
Truck 11	6,217	1152	—	3,551	—2,151
Truck 12	5,194	1112	3	3,427	—1,767
TOTAL	62,486	12132		37,394	—14,106

Table 5 Estimation of rural potable water distribution costs, Monte Patria

Source: Created by the authors

		Coordinates					(4)	(5) = (4)*(3)	(6) = (5)*3
				(1)	(2)	(3)	Average monthly rental value per truck (US$)	Reduction in annual expenditure (US$)	Expenditure reduced by three years (US$)
Municipality	Rural location	X	Y	Budget including VAT (US$)	N° trucks with service contracts	N° trucks to be downgraded / system			
Monte Patria	*Juntas Dos Ríos*	*—30,710231*	*—70,879531*	*$31,337*	*10*	*2*	*$5,791*	*$138,976*	*$416,929*
	Cárcamo 1	*—30,955936*	*—70,887183*	*$17,502*					
	Cárcamo 2	*—30,945603*	*—70,902133*	*$16,373*					
	Las Américas	*—30,673947*	*—70,952508*	*$41,649*					
	Los Laureles	*—30,744561*	*—70,607789*	*$23,049*					
	Las Represas	*—30,746744*	*—70,936231*	–					
	El Palomo	*—30,740119*	*—70,612828*	–					
			TOTAL	*$129,910*					

Table 6 Investment amounts in infrastructure projects (IPs)

Source: Created by the authors

Table 7 shows the portfolio of IPs with their investment amounts and projected expense reductions (projects that were funded and constructed are indicated with an x). One of the main features of including the IPs was that they allowed for the projection of long-term solutions, aligned with the challenges of addressing a slowly occurring disaster, which could not have been tackled solely with the optimization model. It should be noted that the number of days scheduled for distribution per week (in this case, five days) conditions the integrated model; if it is decided to decrease or increase this duration, the scenario-based simulations, establishing that data collection and optimization model parameters must be modified, and the IPs must increase or decrease their capacity. Therefore, the planning phase must be meticulous and consider all viewpoints and interests of the stakeholders. As previously mentioned, this also impacts the levels of deprivation and security the beneficiaries feel.

The study's findings show that municipalities and regional governments widely accepted the proposed solution to the problem. Its implementation demonstrated that fewer trucks could be used in the system in an operational and structural sense. Therefore, the optimization model could be executed in parallel with the PIs, reducing distribution costs and improving the quality of life for the beneficiaries.

Similar to Cole *et al.* (2021), the study emphasizes the importance of effective planning that integrates diverse data and sharing are critical factors for achieving successful outcomes (Bahinipati and Gupta, 2022).

Projections indicate that if all IPs were executed with an updated optimization model, more than 240 families and 960 people would benefit, with an estimated real reduction of 10 trucks from the distribution system (11%). The estimated reduction in expenses is approximately US$2m. The proposed methodology also impacts the control of beneficiaries' health and water quality, as it is easier to control a main delivery point or tank than dispersed points. This contributes to resilience against possible disasters or health issues, determining specific intervention points and timely assistance since all beneficiaries are geo-referenced. Drought preparedness measures increase the adaptive capacity and resilience of communities affected by this situation. The projects' implementation evidenced the favorable reception by beneficiaries and their particular adaptation to the new distribution system, in which they must wait for delivery every five days.

Municipality	Locality	Projects budget VAT included USM$	Executed projects	N° operational trucks contract services	No. of trucks to be reduced	Reduced annual spend US$	Reduced expenditure three years US$
Salamanca	Las Jarillas (alto)	$8.37		5	1	$42	$126
	Las Jarillas (bajo)	$16.25					
	Tencadán	$10.42					
Illapel	El Piche	$38.92		7	1	$42	$126
	Los Perales	$85.43	X				
Los Vilos	Cavilolen	$55.82		4	1	$42	$126
	Cerro Blanco	$16.59					
Monte	Juntas Dos Ríos	$34.73	X	10	2	$84	$252
Patria	Cárcamo 1	$19.39	X				
	Cárcamo 2	$18.14	X				
	Las Américas	$46.15	X				
	Los Laureles	$25.54	X				
	Las Represas	$13.27					
	El Palomo	$8.37					
Punitaqui	Cancha La	$39.43	X	9	2	$84	$252
	Higuerita						
	Las Cruces	$40.99					
Ovalle	Caleta El Toro	$27.69		4	2	$84	$252
	Las Animas	$58.47					
Combarbalá	El Divisadero	$35.63		10	2	$84	$252
	Los Bolones	$11.05					
Coquimbo	Cruz De Caña	$68.28		5	2	$84	$252
	Las Cardas	$115.60					
	Santa Amalia	$59.04	X				
La Higuera	Quebrada Onda	$382.81		4	1	$42	$126
Andacollo	La Chupalla	$218.65	X	3	1	$42	$126
	La Jarilla	$282.22	X				
Vicuña	Chapilca	$87.93		3	1	$42	$126
	El Porotal	$155.65					
La Serena	Condoriaco	$168.66		4	1	$42	$126
	Chacay Alto	$185.34					
Canela	Yerba Loca (1.2.3)	$475.88		6	3	$126	$378
Rio Hurtado	Peñaflor De	$94.02	X	3	1	$42	$126
	Tahuinco						
	Carrizal	$129.05					
Paihuano	El Colorado	$193.43		1	0	$0	$0
		$3,227.20		78	22	$546	$2,772

Table 7 Infrastructure projects (IPs) projected by municipality

Source: Created by the authors

CONCLUSIONS

This research has advanced in establishing a framework to address water scarcity in the Coquimbo Region of Chile, providing a replicable model for other regions facing similar challenges. The census methodology used in this study focused on the comprehensive data collection of 5,519 households benefiting from potable water distribution in the Coquimbo region, Chile. This work established a baseline via a regionally geo-referenced census, using specific forms to record data on water loading and unloading points, trucks and distribution routes. These data were consolidated into a geo-referenced database and integrated into a GIS. This methodology provides a complete and accurate picture of the current situation, providing a solid foundation for informed decision-making and resource optimization.

The main difference between a census methodology and a sampling methodology lies in the comprehensiveness and precision of the data collected. While a census involves collecting data from the entire target population, a sample is based on a representative subset. The advantages of the census approach include minimizing selection bias, achieving high precision and accuracy in the data and providing detailed microlevel insights that allow for more accurate analysis. The coordination of multiple actors, including municipalities and the regional government, was crucial for the success of the census and for minimizing nonresponse bias, an issue present in various studies.

Consolidating data in a GIS and geo-referencing the collected information were essential for managing the large volume of data and enabling detailed analysis and geospatial visualization. This approach provided a solution that improved operational efficiency, reduced costs and demonstrated that implementing IPs is an effective strategy for enhancing water resource management in rural areas, especially in the context of drought and with a long-term perspective. The continuation of such projects and investment in research and development (R&D) are crucial for ensuring water resources' future availability and sustainability.

Our research has provided practical and efficient solutions for potable water distribution in the Coquimbo Region and laid the groundwork for future R&D in water resource management. Collaboration between academic institutions, governments and local communities is essential to tackle the challenges of water scarcity and ensure a safe and sustainable potable water supply for all. The implementation of information systems and the standardization of procedures proved essential for improving transparency and operational efficiency. These innovations generated significant economic savings and facilitated more effective and transparent management of the water distribution system. Adopting digital platforms and real-time monitoring technologies would allow for better coordination of activities and a faster response to needs and changes in water demand. The IPs for water distribution networks, which continued to rely on trucks due to the scarcity of natural sources and formed an "integrated model," enabled a long-term approach to the problem. In this sense, continuously identifying alternative water sources, such as wells and irrigation channels, would expand supply capacity, providing greater resilience to fluctuations in water resource availability and potential operational failures of the trucks. This proactive approach to managing alternative sources is fundamental to ensuring the long-term sustainability of the potable water distribution system. Interinstitutional collaboration was a key component of the success of this and future studies, both for theoretical planning and field implementation. Coordination among different levels of government, academic institutions and local communities allowed for effective implementation and quick adaptation to operational challenges. In addition, community education and engagement, along with ongoing political and financial support, are essential to ensure these solutions' successful implementation and expansion.

This research can be useful for other regions facing water scarcity, as the model applies to rural areas with water access issues, whether drought or resource shortages. Such initiatives can serve as examples for developing policies and strategies for water resource management in vulnerable areas, improving efficiency and reducing costs. However, it requires the coordination of various stakeholders, and a significant investment is necessary, which could be an obstacle for regions with budget constraints. Therefore, this work can serve as a guide on the steps to follow to achieve successful implementation.

Recommendations for future research highlight the need to continue exploring and developing new technologies and approaches for water resource management. The integration of smart technologies and the expansion of complementary technological solutions can offer even greater improvements in the efficiency and sustainability of the system. In the era of Industry 4.0 and smart cities, implementing real-time monitoring systems, such as sensors and automated management systems, to improve precision and efficiency can result in greater impacts for these initiatives. It would be interesting to conduct comparative studies in regions affected by slow-evolving disasters to validate and adjust the model. This could address potential limitations of applying a solution when water demand is variable due to climatic, socioeconomic or demographic conditions. Other future lines of research should consider the ecological variable in addition to a sociotechnical perspective. Developing studies with a socio-technical-ecological approach within the framework of the sustainable development of society is a challenge, which generates questions related to:

Q1. How to declare, simulate and/or measure the ecological impact of the optimization models proposed in the area?

Q2. How to design the infrastructure ("natural," "built," "social," "human") so that social self-organization and, therefore, resilience, is integrated into the environment?

Q3. How does the ecological "context" that can change quickly or slowly influence the socio-technical system and adaptability to hazards?

Q4. How do political dynamics react to ecological changes to better react to hazards and potential disasters?

Q5. What is the impact/role of technology in the interaction of socio-ecological systems in preparing for and resilience to creeping hazards or disasters?

Understanding how processes in nature modify and/or reconfigure sociotechnical analysis or conditions and incorporating this comprehensive vision into research frameworks would give a better interpretation to the dynamics of hazards and disasters in humanitarian logistics. In the same line, future studies could determine the resilience of the beneficiary groups and the different factors that could affect this construct. In conclusion, our research has helped demonstrate to the academic and humanitarian logistics communities that careful planning, innovative technologies and collaboration among multiple stakeholders can significantly transform water resource management in rural areas. This comprehensive and systematic approach not only improves the availability and quality of potable water but also ensures the system's resilience and sustainability in the face of future challenges. The established model can serve as a valuable reference for other regions and countries facing similar issues, contributing to global water security and the well-being of rural communities.

NOTES

1 In Chile, drinking water collection, treatment, and distribution are concessioned to private companies (sanitary enterprises), which charge per m3 consumed within their area of operation.

2 The RPW systems are formed by a group of families that, in an organized and legal way, apply for the construction of a drinking water treatment and distribution system, which has its source and is not located within the area of operation of any sanitary company.

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APPENDIX1

Route Form

I. Identification of the Route

Destination		Province	
Starting point route		Commune	
ID combination of routes		Locality	

II. Surveyor Identification

First Name, Last Name		Date	

III. Operation

Initial KM		Start Time First Time		Start Time Return	
Final KM		End Time First Time		Final Time Return	
Route		Time to go		Return time	

IV. Morphology (indicate route)

Land			Asphalt			Another			
Gravel			Bischofita			State	B	R	M

V. Conditions of the Road (indicate Route ID)

Nº of Vias			Fog Zone			Maximum Speed	
Nº of Bridges			Badenes			Allowed	
Nº of Slopes (km)						Effective	

VI. Accessibility (in case of)

Rain	If	No	N/A	Aljibe truck	If	No	→	Tonnage
Snow	If	No	N/A	Van	If	No		
Earthquake	If	No	N/A	Pedestrian	If	No		

VII. Georeferencing

Digital Photography

Observations

Charging Point Form

I. Charging Point Identification

rst Name Surname - Company Name				Way of Loading	
RUN - RUT		Province		Faucet	
UTM location	West	Commune		Water inlet	
	South	Locality		Deep Well	
	Contour			Pressure pipe	

II. Surveyor Identification

First Name, Last Name		Date	

III. Property

Municipality		Waters of the Valley	
APR		Another	

IV. Equipment

Bomb		Water stabilizer	
Valves		Chlorine Meter	
Flowmeter		Accessories	

V. Supply

Recovery Time		Unit	Week	Day	Hours

VI. Georeferencing

Digital Photography

Observations

Truck File

I. Truck Identification

First Name, Last Name Driver					
ID - Patent		Province		Property	
Parking - UTM Location	East	Commune			
	South	Locality			

II. Operation

Initial KM		Start Time		Start Time Return	
Final KM		End Time		Final Time Return	
		Time of the Route		Route Completed	

III. Equipment

Radio		Bomb		Roadworthiness check	
Winter Box		Hoses			
GPS		Water stabilizer			

IV. Characteristics

Volumetric Capacity		Charging Start Time	
		Final Loading Time	

V. Georeferencing

Digital Photography

Observations

Discharge Point Form

I. Identification Point of Download

st Name Surname - Company Nam				Type*	
RUN - RUT		Province		Family Group	
UTM location	X (West)	Commune			
	And (South)	Locality			
	Contour				

II. Surveyor Identification

First Name, Last Name		Date	

III. Storage

Community		Number of Ponds			Material			
Individual		Reception Capacity	Lts		State	B	R	M
		Instrumentation	If	No				

IV. Sanitary Facilities - Accessories and Operation

Pipe Network		Pumping		Distance between Pond - Point of Application		
Gravity		Manual		Bathroom	Kitchen	Washing
Sist. Purification		ferris wheel or well				

V. Supplies

Frequency		Unit	Week	Day	Month	
Regularity	If	No	Amount of Liters		Duration of Download	

VI. Use - Priority of Use and Impact

Use								
To cook		People's Consumption		Other (specify)		Satisfaction		
Toilet Enclosures		Animal Consumption				Frequency	If	No
Personal hygiene		Irrigation				Quality	If	No

VII. Georeferencing

Digital Photography

Observations

APPENDIX 2

	Route Locality	No. HOMES	No. beneficiaries (persons)	Dem. Water/ day día	Dem. Water/ week	Route demand	Route week KM	Medium speed	Download time (hours)	Travel time (hours)	Route time (hours)
1	Antiguaico	3	17	510	3.570	8.190	40	50	2.15	0:48	3:03
	Cruce Tome Alto	1	1	30	210						
	Bellavista	5	21	630	4.410						
2	Pedregal	2	5	150	1.050	18.060	120	45	5:57	2:40	8:37
	Mostacilla	8	29	870	6.090						
	Bellavista De Careén	11	52	1.560	10.920						
	Huana	9	40	1.200	8.400						
	Huana Alto	1	5	150	1.050						
3	Parcela Huana	1	2	60	420	22.470	50	40	6:45	1:15	8:00
	Moñozana	8	32	960	6.720						
	Las Ruinas	7	27	810	5.670						
	Chupa Barro	1	1	30	210						
4	Caércamo	15	49	1.470	10.290	3.780	80	40	3:45	2:00	5:45
	Villa El Palqui	4	18	540	3.780						
	Villa La Represa	11	47	1.410	9.870						
	Puente El Plomo	1	5	150	1.050						
5	Peñ´on Sur	1	2	60	420	21.000~	30	45	5:45	0:40	6:25
	Santa Julia	1	5	150	1.050						
	Siete Casas	1	5	150	1.050						
	Cementario	1	3	90	630						
	Bomba El Palqui	3	15	450	3.150						
6	Quebrada El Milagro	16	67	2.010	14.070	14.070	10	45	4:00	0:13	4:13
7	El Palqui	19	96	2.880	20.160	20.160	30	35	6:20	0:51	7:11
8	El Trapiche	6	19	570	3990	4.620	30	40	1:45	0:45	2:30
	La Coipa	1	3	90	630						
9	Apr Hu Atulame	1	60	1800	12600	12.600	30	40	1:00	0:45	1:45
	Huatulame	28	83	2.490	17.430						
10	Los Potreros	1	2	60	420						
11	Huallaquil	5	14	420	2940	5.880	53	40	2:30	1:19	3:49
	Piedras Bonitas	5	14	420	2.940						
12	Palos Quemados	36	160	4.800	33.600	33.600	15	15	7:12	1:00	8:12
13	Apr Los Tapias	1	240	7.200	50.400	50.400	40	40	1:00	1:00	2:00
14	Apr Los Morales	1	120	3.600	25.200	25.200	42	40	1:00	1:03	2:03

15	Huanilla	36	151	4.530	31.710	31.710	60	30	6:36	2:00	8:36
	Chacarilla	7	17	510	3.570						
	Los Morales	8	18	540	3.780						
16	Los Tapia	1	5	150	1.050	15.120	140	40	5:12	3:30	8:42
	Chañaral Alto	6	24	720	5.040						
	El Encantado	2	8	240	1.680						
17	Los Rojas	17	77	2.310	16.170	16.170	40	40	4:15	1:00	5:15
	El Palomo	15	50	1.500	10.500						
	Los Clonquis	2	12	360	2.520						
18	Juntas	13	55	1.650	11.550	30.030	120	40	5:33	3:00	8:33
	Los Laureles	6	22	660	4.620						
	Sol De Las Praderas	1	4	120	840						
19	La Moraleda	22	89	2.670	18.690	18.690	60	35	5:30	1:42	7:12
20	La Cisterna	5	20	600	4.200	4.200	102	40	1:15	2:33	3:48
21	Macono Alto	5	16	480	3.360	3.360	120	40	1:15	3:00	4:15
	El Vertedero	2	2	60							
22	Los Jofreces	4	19	570	1.590	1.590	60	40	4:00	1:30	5:30
	Mal Paso	3	11	330							
	Monte Patria	7	21	630							
23	Apr Monte Patria	1	48	1.440	1.440	1.440	14	30	1:00	0:28	1:28
	La Higuera Baja	4	13	390							
	La Laja	4	17	510							
24	Minas De Huana	1	6	180	1.770	1.770	50	30	4:15	1:40	5:55
	Peralito	6	17	510							
	Pueblo Hundido	2	6	180							
25	Las Cardas	13	43	1.290	1.290	1.290	60	40	3:15	1:30	4:45
26	Santa Rosa	1	4	120	2.040	2.040	70	35	3:15	2:00	5:15
	Tamancura	12	64	1.920							
27	Tomeé Bajo	21	83	2.490	2.490	2.490	20	30	5:15	0:40	5:55
28	Laguna Verde	4	9	270	270	270	54	40	1:00	1:21	2:21
	Rapelcillo	2	7	210							
29	Colliguay	1	6	180	420	420	123	40	0:45	3:04	3:49
	Careén	1	1	30							
30	Aguas Frias	3	14	420	540	540	66	35	1:00	1:53	2:53
	Cerrillos De Rapel	1	4	120							

Table A1 Route matrix, Monte Patria commune

Source: Created by the authors