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The Water Management Impacts of Large-Scale Mining Operations: A Social and Environmental Perspective

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Abstract: This study investigates water consumption in two areas with limited water resources—the Salar de Atacama and Salar de Atacama-Vertiente Pacifico basins in Chile's Antofagasta Region—with the aim of developing strategies that incorporate social and environmental aspects into water management. A qualitative approach was employed that involved a focus group with twelve water management representatives and surveys of the general population (468 responses). Additionally, the current state of water rights in the two basins was examined and the feasibility of the proposed strategies was assessed. The findings reveal that the mining industry's development approach is mostly viewed as negative, mainly due to inadequate community engagement, confidential consumption data, and limited government oversight. The quantitative findings indicate that 53.8% of respondents see the main obstacle as the lack of a solution satisfying both parties. Additionally, 35.3%, 24.4%, and 22.4% believe transparency, objective information provision, and detailed resource usage disclosure by mining companies would help. Adopting a comprehensive water stewardship approach that considers social and environmental factors would enable a novel contribution to a more effective and sustainable water resource management system in northern Chile, mitigating communities' negative perceptions of the industry and facilitating the integration of communities and involved agents. Therefore, improved management and transparent collaboration among stakeholders are essential for responsible water resource use in mining.

Keywords: sustainability; communities; engagement; social perspectives; water stewardship

Citation: Arenas-Collao, K.; Valdés-González, H.; Reyes-Bozo, L.; Salazar, J.L. The Water Management Impacts of Large-Scale Mining Operations: A Social and Environmental Perspective. *Water* **2024**, *16*, 1745. https://doi.org/10.3390/w16121745

Academic Editors: Yaning Chen, Chenggang Zhu, Gonghuan Fang, Zhi Li, Weili Duan and Yupeng Li

Received: 28 May 2024
Revised: 16 June 2024
Accepted: 18 June 2024
Published: 20 June 2024

1. Introduction

Each year, the effect of climate change on the planet becomes more evident. Different areas around the world have been affected by more extreme temperatures, droughts, flooding, and other problems. These problems have been exacerbated by a misguided approach to water resource management; this approach is driven by the consideration of water more as an economic good than as an essential resource for the existence of life, according to [1]. These environmental problems cause considerable difficulties in industries that require a fixed and constant supply of water throughout the year, and that cannot be suspended as they contribute to public well-being in various ways, such as by providing employment opportunities, food production, or contributions to a country's GDP.

Mining is one example of these industries as mining operations work constantly, day and night, every day of the year. Due to this demanding pace, the supply of water is a fixed cost, rather than a variable cost, during the life of the mine. Furthermore, since mining typically takes place in inhospitable areas, it must often deal with water scarcity while also avoiding an excess of water in the operating area [2]. Hydrological studies are therefore carried out by mining companies in order to establish the water balance and ensure the

availability of the resource. However, since these studies do not consider the social and environmental factors beyond those indicated in water codes, there is often a divergence between what companies are authorized to extract and what it is prudent to extract [2].

As the mining industry has relied on the availability of water in the areas where its operations are located, many operations have been negatively affected by the long-term use of surface and groundwater [3]. This limitation on the use of water, together with the growing need to involve communities in water management to ensure local benefits, has prompted the industry to search for solutions to counteract water scarcity, such as reuse, usage of lower volumes of water, or addressing water issues at catchment scale [4].

1.1. Water Resources Impacts of Large-Scale Mining

In certain areas, mining activity can significantly affect the demand for water. This is often the case in remote regions with low population densities, where mining represents the primary economic activity. The resulting increase in water demand is a significant factor in the environmental impact on local hydrological basins, as it can exceed the ecological flow of the region by up to 46 times [5]. Furthermore, studies have demonstrated that excess mine water discharge in some areas can lead to floods and tailings dam breaches [6,7]. These are just two examples of the diverse risks that nearby communities face due to large-scale mining operations.

Typically, the hydrological impact in mining areas is gauged by measuring the level of contamination and the comparison of the available water flow versus the water flow demanded by the sector in an environmental impact assessment (EIA) study. As part of the assessment, actions are proposed to compensate, mitigate, and control the affected environment. Although regulations require mining companies to carry out the assessment, in Chile and other countries, companies are not obliged to comply with the promised actions that would protect the environment due to a lack of regulation and supervision [8].

1.2. Social License to Operate and Participative Engagement

The social license to operate (SLO) can be defined as an intangible agreement between the shareholders of an organization and communities, in which the latter grants their approval to carry out a certain project [9]. Consequently, it is often said that the license must be earned and prioritized to maintain its status over time [10]. Although it has been found that gaining an SLO has come to present less of a challenge to the mining industry in recent years, it still ranks third among the top ten challenges that the mining industry must face [11], indicating its importance for the industry.

One of the relevant practices for obtaining an SLO is engagement with external stakeholders, which mining companies can develop through meetings with nearby communities that often comprise Indigenous People. These meetings aim to communicate project characteristics and collect concerns that communities may have. The primary purpose of this relationship building is to obtain the free prior and informed consent (FPIC) of the communities and establish a memorandum of understanding (MOU) among the parties involved. However, the main challenge in establishing such relationships is that mining companies typically focus primarily on obtaining the FPIC rather than establishing meaningful and cooperative meetings with communities [12]. Previous studies have shown that conducting participatory engagement with a multidimensional consideration of nearby communities can improve the social performance of mining companies [12–14].

1.3. Rights of Water Usage in Chile

In Chile, water is a resource that can be granted through a right to use it. These rights are usually expressed in units of volume per unit of time, allowing individuals to decide and utilize this flow according to their convenience or industry [15–17]. The water rights have two classifications, based on their consumption or the location of the water. The first classification includes consumptive or non-consumptive rights. In consumptive rights, the beneficiary of the right can fully consume the resource, whereas in non-consumptive rights,

the resource must be returned to its natural flow. In addition, water rights are classified as surface or groundwater. Surface sources are those water sources that appear on the earth's surface, such as rivers, lakes, lagoons, or reservoirs, while groundwater sources are those hidden below the earth's surface [15].

According to the Water Atlas collated by the Chilean General Water Directorate (DGA) [15], as of August 2015, 52,581 water rights were granted, of which 81.7% are consumptive and 18.3% are non-consumptive. Within this, the flow of groundwater delivered to the same date corresponds to 467.3 cubic meters per second, while that of surface water amounts to 40,007.71 cubic meters per second. The majority of granted surface water rights correspond to non-consumptive types whereas the groundwater rights are mostly consumptive and definitive [15]. As a result of this legislation, in regions of Chile where mining is the primary economic activity, the majority of water rights are allocated to mining companies, which can leave other stakeholders with limited access to water and make it challenging to implement holistic approaches.

In summary, in Chile (and, it can be expected, in other countries), the integration of environmental and social factors in hydrological basins where mining projects are developed has not been considered as an important part of creating strategies to optimize the use of freshwater. The mining industry needs to reduce its hydrological impact [2] and enhance its social acceptability by integrating the perceptions of previously marginalized communities into the development of more appropriate water-use strategies. This study contributes by addressing the critical gap in water resource management in the mining regions of northern Chile. It provides a comprehensive analysis of the deficiencies in current practices, highlighting the necessity of integrating social and environmental factors. By proposing a strategic framework that includes effective communication policies, investment in water reuse technologies, and fostering community engagement, this research offers a holistic approach to sustainable water management. The findings and recommendations not only advance the theoretical understanding of resource management in arid regions but also provide practical insights for policymakers, industry stakeholders, and community leaders aiming to mitigate water scarcity and enhance social acceptability in mining operations. Therefore, strategic guidelines are proposed to integrate the social and environmental assessment of local basins into the planning of water resource use, based on social perceptions and formal hydrological parameters of these basins. The aim of this study is to analyze the applicability of proposed strategies from the perspective of the different agents who utilize the water resource, to integrate the environmental and social factors.

2. Methodology

2.1. Overview

In this study, a qualitative approach was adopted to understand the perspectives of different actors in social and environmental dimensions. Initially, individual interviews were conducted with representatives from the mining area, and these responses were then consolidated via a focus group. The qualitative findings were then taken into account for the design of a survey that was then administered to members of the general population. With this second instrument, the aim was to understand the perspective of the population regarding specific strategies identified by focus group participants [18–20].

2.2. Study Location

The Salar de Atacama and Salar de Atacama-Vertiente Pacífico basins are located in the Antofagasta region, Chile. They are limited by the Domeyko mountain range and other endorheic basins on the border with Argentina and Bolivia. In their surroundings, communities, mainly indigenous, coexist whose development depends on the water available in the rivers that originate from the Atacama and Punta Negra salt flats. The importance of these basins lies in that their water flow is the main source of this resource in delicate ecosystems under extreme conditions, such as hypersaline lagoons [21]. Through the review of water rights granted in the basins, it was found that most of these rights were

granted to private mining companies, while the second largest proportion corresponds to rights granted to state-owned mining companies. Currently, four mining companies hold the largest amount of water extraction rights in this area. Figure 1 illustrates the distribution of total water rights, including consumptive and non-consumptive rights, in the study area. Figure 2 shows a map of where the Salares are located in the country.

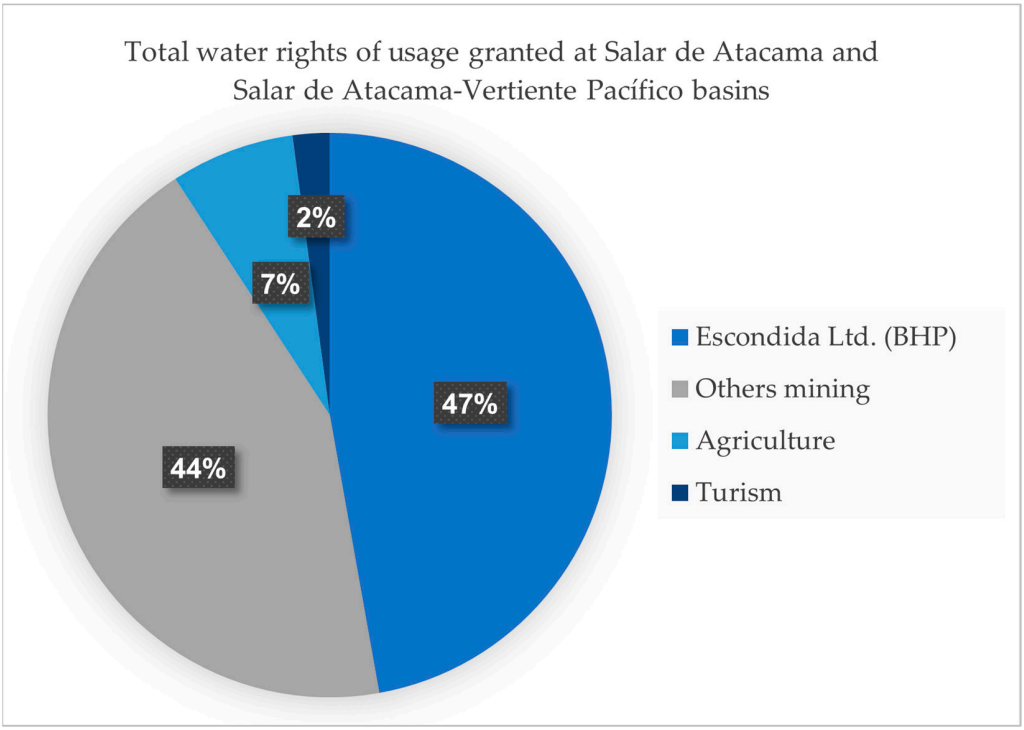

Figure 1. Total water rights of usage granted at Salar de Atacama and Salar de Atacama-Vertiente Pacífico basins.

2.3. Interviews and Focus Group

Possible informants from various hierarchical levels and roles within the studied water system were contacted to include diverse perspectives. The participants comprised four mining engineers in c-suite positions and six mining engineers in manager positions at the largest mining companies present in the zone, both private and state-owned, along with one local resident and one farmer. The age of the participants ranged from 27 to 55 years old. All the mining-related interviewees had pursued graduate studies, while the local resident and the farmer held an undergraduate degree in a field other than mining.

The interview questions were developed following non-participant observations. One of the researchers carried out scheduled visits to various mining operations over a period of 12 months in order to conduct the observations and thereby define areas of interest and interview questions.

The participants were interviewed individually via video calls that were recorded and transcribed. Each interview lasted approximately 45 mins. The interview had three sections aimed at finding out about the level of understanding, potential proposals, and the risks and disadvantages associated with the proposed strategies. The complete instrument can be found in Appendix A. Following an initial analysis of the interviews, a focus group was carried out with six of the participants online in order to explore and consolidate certain themes in more depth. In addition, some participants sent further comments via email.

The transcribed data from the interviews and focus group, together with the emailed comments, were systematically analyzed by two of the researchers together. Following an initial reading to familiarize themselves with the texts, segments of text were coded to identify important features. These codes were then grouped into broader themes, which were refined and named based on their relevance and support from the data.

Figure 2. The locations of Salar de Atacama and Salar de Atacama-Vertiente Pacifico basins in Chile.

The findings from the interviews and focus groups were triangulated with data from the non-participant observations and analysis of documentation, such as internal reports from different mining companies.

2.4. Survey

The survey was conducted online using a non-probabilistic sampling method. The survey was distributed among the selected stakeholders for this purpose. A total of 468 effective responses were obtained from a sample of 750 individuals selected from the

central-north region of Chile, who voluntarily participated. The respondents represented a wide age range, from 20 to 55 years, and varied levels of education.

The survey was used to understand the general population's perception of the identified strategies and approaches to address the problem. It consisted of closed-ended questions with response options generated from the textual data of the interviewees. Like the interview, the survey consisted of three sections aimed at finding out about the level of understanding, potential proposals, and the risks and disadvantages associated with the proposed strategies. The survey can be found in Appendix B.

Initially, the responses to the interviews and focus group were considered as entry perceptions to derive contextualized questions for the survey instrument. From this first exercise, the central ideas expressed by each interviewee, specifically from Sections 2 and 3, were taken to obtain the main proposed strategies, which were grouped according to similarity. This process is illustrated in Figure 3.

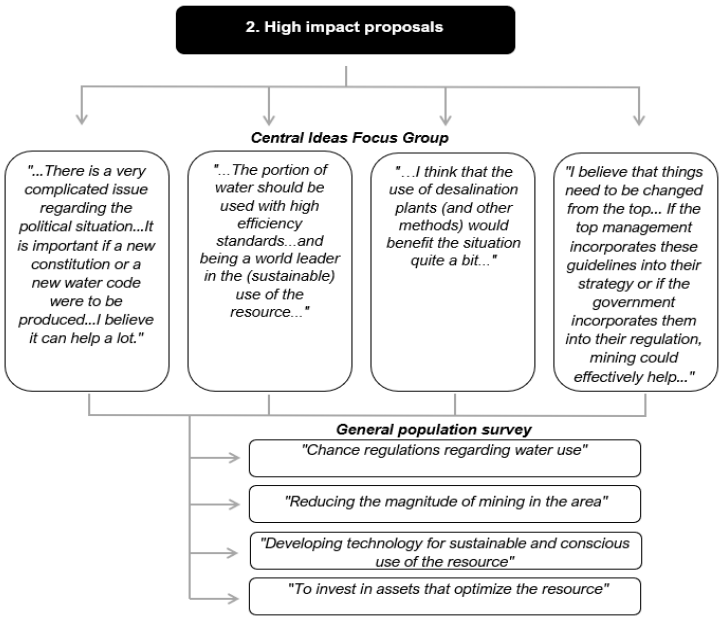

Figure 3. Selection process of alternatives for the survey; in this example, the development of the question "Which of the following options do you think is the best strategy to improve resource management? Consider that ideally this strategy should have a high impact and be short-term".

These generalities were subsequently taken as alternatives for the survey. The *"prefer not to answer"* option was included for all questions in order to prevent respondents from feeling obliged to choose any of the previous options. The validation of the qualitative analysis was carried out through consultation with two experts in water management and resource management areas, respectively.

2.5. Ethical Considerations

Following the principles of the Declaration of Helsinki of 1975 [22], the twelve interviewees in this study freely provided informed consent. The informed consent form outlined the possible risks of participating in this activity, clarified that the questions were intended solely to gather their opinions on the use of water resources for research purposes, and guaranteed the protection, privacy, and anonymization of their personal data, such as age or education level. Since the interviews aimed to obtain their professional assessments and insights on a topic within the industry they were involved in, this activity was exempt from Ethics Board Review according to Chilean laws and international standards [23–25].

In addition, the surveyed population also willingly provided informed consent, which stated that the protection, privacy, and anonymization of their personal data, such as their current region of residence or age, were ensured. The informed consent also explained the

purpose of this study and how the data would be used. Since the researchers had no direct interaction with the surveyed population, this activity was also exempt from the Ethics Board Review.

It is declared that the present study has no conflicts of interest and has not been funded by any of the companies present in the area.

3. Results

The following section presents the results collected from the application of the research instruments. In order to avoid unnecessarily lengthening the text, only the most relevant questions are analyzed.

3.1. Characterization and Understanding of the Current Situation

The majority of participants in the focus group agreed with the notion that the mining industry ought to seek new alternatives for the utilization of water resources. This sentiment was conveyed through various opinions given by the participants, such as "Let's start with the fact that industrial activity will always use water…now, in the current reality…the use of water by mining should be optimized and minimized from natural sources…ensuring that other participants have access to the resource" (Interviewee 1) and "I believe we are in a critical state with fresh water…I think the industry should explore alternative ways to obtain water" (Interviewee 9). One of the participants mentioned poor management as a problem: "I believe that the management has not been very good…since we have had many protests because during the summer, several water cuts occurred and the water was cut off for more than a week" (Interviewee 4). This opinion was widely accepted by the surveyed population (n = 468), of whom 66% considered that the management of the water resource is carried out in a "very bad" or "bad" way.

Regarding the water management, when the focus group participants were asked to identify main deficiencies and their causes, their responses varied and they mentioned "poor communication among the agents who use the resource"; "every agent is seeking their own interests"; and "mining operations should be scaled down". In comparison, 73.1% of the surveyed population considered that the main cause of poor management was that "every agent is seeking their own interests".

Finally, when asked who were the key agents or factors to facilitate taking the population's perceptions into account, two members of the focus group indicated that the main agent corresponds to "Mining executives", while one considered that it should be "Legal factors". However, 44.9% of the surveyed individuals considered that the most relevant agent is "Shareholders of mining companies".

3.2. High Impact Proposals

Concerning the high-impact and short-term strategies that the mining industry should adopt, the twelve participants of the focus group proposed different alternatives, but they agreed that these guidelines should come from an agent with power over management. This stance was expressed through statements such as: "The political situation is complicated… If a new constitution (The Chilean constitution is currently under review.) or a new water code were to be produced, I believe it could help a lot" (Interviewee 8), and "I believe that things need to be changed from the top…If the top management incorporates these guidelines into their strategy or if the government incorporates them into their regulation, mining could effectively help" (Interviewee 10). Amongst the survey respondents, there was more variation with regard to which strategy was considered to be most important. A total of 34% of the population responded that the best strategy would be to "Invest in assets that optimize the resource"; 32.7% responded that it was "Developing technology for sustainable and conscious use of the resource"; and 29.5% responded that the "Regulations regarding water use" should be changed.

In relation to the proposed change to create agreements between companies and communities, all interviewees commented that it should be feasible or "work". For instance,

one commented that "I think that's how it should ideally be... These types of proposals allow both parties to create a positive environment for future dialogues" (Interviewee 3). However, they each perceived different constraints for this plan, for example, mentioning that "The main disadvantage I see is the time it may take to reach a feasible agreement" (Interviewee 12) and "I'm not so clear how effective it could be though... One disadvantage could be that the conflict between the parties gets worse." (Interviewee 11). In the survey, these concerns were also reflected. A total of 39.7% of the respondents considered that "It would work with conditions", while 21.8% agreed that "Yes, I think it would work", and 21.2% held that "It would work, but it would take a lot of time".

3.3. Analysis of the New Strategies

Regarding the threats and opportunities for the strategies proposed in previous section, each member of the focus group expressed a different analysis. These ranged from opinions such as "I do not believe that there are risks or threats to people or jobs. On the contrary, I believe it is an opportunity" (Interviewee 2) to "[There could be] difficulty in meeting production or economic goals which could make the project unfeasible... I believe that government assistance is needed to transform the industry culturally" (Interviewee 5). In the survey, participants were asked to choose between "Project unfeasibility"; "Availability of job opportunities"; "Damage to the mining industry's image"; "That it may be too late to renew the (water) resource"; or "Do not consider there to be a threat, as it is an opportunity". The responses were mainly in two distinct categories: 40.4% indicated that the main threat is "the unfeasibility of mining projects", while 28.8% indicated that "there are no threats, as it is an opportunity for improvement".

Finally, in connection with the obstacles and facilitators for implementing these new strategies, the focus group participants commented that the main obstacle is "Industry secrecy" and the main facilitator would correspond to "Transparency of the industry towards communities". These generalizations were derived from opinions such as: "There is no webpage or place where the benefits that mining grants to society are objectively published" (Interviewee 6) and "It would facilitate the process to make known in more detail what the companies do and the impacts that could occur. The main obstacle is that, due to the lack of transparency, there are people who want them to leave, no matter what they offer." (Interviewee 7). In order to better understand the population's perception of this topic, questions were asked specifically about a facilitator and an obstacle. The findings show that 53.8% of respondents believe that the main obstacle is "the lack of a solution that satisfies both parties", while 35.3%, 24.4%, and 22.4% believe that transparency in the actions of mining companies, the provision of objective general information by mining companies to people, and detailed disclosure of how the industry uses resources, respectively, would facilitate the process.

3.4. Analysis of Feasibility and Prioritization of Strategies

In the context of water scarcity and mineral bodies with increasingly lower grades, which require processing larger quantities of ore to achieve the same production output [26], the strategy of incorporating assets that enable the optimization of resources represents a fast and cost-effective alternative for reducing the use of continental waters.

In this regard, the Chilean Copper Commission (COCHILCO) [27] states in its report "Projections of electricity and water consumption in copper mining until 2032" that although 73% of reused water is currently used in mining, 70% of the remaining 27% of "new inputs" correspond to continental waters. These figures indicate that the trend of most mining companies continues to focus on the use of continental waters and recirculation, rather than investing in assets to use seawater or to increase the resource stockpile.

This approach may be due to the fact that these assets mostly require vast amounts of capital [28] as they involve pumping water from coastal to mountainous areas, using processes with reduced efficiency, and increasing the cost per cubic meter of water by approximately three times compared to the extraction of continental waters [29]. In addition,

current technology is not efficient enough to make this a profitable alternative in most cases [30]. For example, it is estimated that a desalination plant requires an investment of between USD 125 and 200 million [28]. Despite these challenges, large mining companies are willing to invest this capital to become a "good neighbor" to communities and not overexploit continental resources. COCHILCO projects, through a Montecarlo simulation, that by 2032, 68% of the water used by mining will come from seawater [27].

In relation to the regulatory change in water use, several authors have argued that the country suffers from an excess of water rights' concessions [8–31], which has generated conflicts between communities and mining companies. This situation is due to the fact that the regulations consider water as a public use good, but also as an economic good whose rights can be granted to individuals through free concessions without state intervention. This contradiction has reached a critical level as in each region of the country, multiple companies own a large portion of the rights to use this resource [32]. In the case of the Antofagasta region, the situation is particularly critical since there is an extreme water deficit that negatively affects people's quality of life and social development, and exacerbates desertification [33]. Therefore, prioritizing water as a national public use good over its commercial use would help mitigate the negative effects of water rights concessions and encourage the industry to seek other alternatives.

In the development of feasible agreements through participatory engagement between communities and mining companies, there are successful cases in which both parties coexist in a situation of respect and mutual benefit. For example, the mining company Sierra Gorda SCM, located less than 1 km from the homonymous borough, has managed to sign agreements with its neighbors through dialogue tables on issues of employability, environmental education, and community relations. Their relationship with the community has been highlighted as an example of corporate social responsibility due to their transparency, commitment, and immersion in the community [34]. Therefore, this strategy can be highly effective as long as companies are willing to share and significantly commit to communities. Among the factors that hinder a good relationship between these agents are the lack of direct communication, impartiality, ignorance of the community's expectations, and the lack of benefits or well-being provided to the community by the mining company.

In order to address the problem of water use in the mining industry in Chile, specific strategies must be prioritized. First, the industry must seek new technologies and ways to reuse water to reduce water stress in watersheds and mitigate the environmental damage caused by the consumption of continental waters. Additionally, it is crucial for mining companies to establish strong relationships with neighboring communities, actively engaging in promoting progress and well-being in the community. Finally, the Chilean government must consider water resources as a common consumable good and not just as an economic good. However, it is acknowledged that this last strategy may be difficult to implement due to the country's complex political climate [35].

4. Discussion and Findings

Concerning the stage of characterization and understanding of the reality, the focus group and the surveyed individuals agree that the management of water resources in Chile is carried out inadequately; the surveyed population considers that this is due to the pursuit of individual interests by the agents involved. These findings confirm those from previous studies conducted in Chile such as those by Rivera et al. [5] and Aitken et al. [8]. These authors also note that the current management does not consider aspects such as the maintenance of the ecological flow, that the current regulations are inadequate, and that there is an excessive granting of water rights.

Regarding the stage of high-impact proposals, despite three of the twelve focus group members being active collaborators in the mining industry, they all presented different proposals to address the issue. Among the options, investment in assets that optimize water use or increase the availability of the water resource stands out, since it had a high degree of acceptance among respondents. According to the analysis of strategies and

their prioritization, this alternative was configured as one of the most feasible and with the greatest impact. However, its main disadvantage is the high investment of resources necessary for its implementation, which suggests the need to establish participatory engagement to obtain feasible agreements with communities to make its execution viable. In this regard, the majority of focus group members indicate that the strategy could work, albeit under certain conditions. These results are consistent with the conclusions of Rodríguez et al. [36], who highlighted the importance of establishing direct and mutually beneficial communication relationships with communities to obtain and maintain SLO. These results are also supported by the projection made by EY [37], where the main risk and opportunity that the mining industry is facing nowadays is to incorporate environmental, social, and governance (ESG) practices.

In the phase of alertness towards transformations, the surveyed population expressed their main concern regarding the proposed strategies as the possible negative impact on the economic viability of mining projects. However, a significant proportion of them consider these strategies as an opportunity rather than a threat. These results are consistent with those from studies conducted by Martínez Varas [28] and Ahmadvand et al. [30]. These authors have pointed out that the high investment required to implement this type of technology can affect the expected profits of a project. They also suggest that desalination represents an opportunity for improvement, as it is not yet fully optimized, and it is crucial to reduce energy consumption since it constitutes the main variable cost of the process.

The identified gaps should be addressed through a holistic approach that considers water as a scarce resource in a desert region, essential for the development of all involved parties. Additionally, it is important to promote transparency and close ties between the mining industry and the community, and to encourage collaboration to understand and meet the needs of both parties. Finally, it is crucial for the Chilean government to monitor and enforce compliance with regulations to reduce conflicts between stakeholders and ensure the proper distribution and management of water resources. In this regard, the findings of this study demonstrate the importance of considering the impact of large-scale mining operations on water resource management for the region as a whole. To ensure sustainable water management, understanding of its management must extend beyond mere data collection and recording, thus necessitating social participation and public dialogue.

Limitations of the Study

As with all research, these findings must be interpreted considering the limitations of the methodology used. The sample size of the focus group was relatively small and their comments may not be representative of others working in the field. The reliance on voluntary participation for the survey introduces potential bias, as individuals with strong opinions on water management or mining might be more inclined to participate, potentially underrepresenting other important groups. Moreover, there was no control for possibly relevant individual variables. This study's geographic focus on the Salar de Atacama and Salar de Atacama-Vertiente Pacífico basins in Antofagasta may not be representative of other mining regions with different environmental and social conditions. In Section 5.1, we consider how future research could address these limitations.

5. Conclusions

The current investigation has identified deficiencies in the management of water resources in northern Chile, particularly in integrating social and environmental factors. This study examined various proposed strategies from the perspective of different stakeholders. The findings indicate that water management is perceived as deficient due to the pursuit of individual interests. Legal factors and mining executives were highlighted as crucial for improving this perception. The best strategy identified involves investing in assets for water reuse, generating new water stocks, and implementing effective communication policies with communities and resource management agents. The primary threat to these

strategies is the high capital required, making some mining projects infeasible. Despite this, both industry participants and the general population view these strategies as opportunities for improvement. Enhancing the transparency and trust of the industry is seen as a key facilitator, while obstacles include the lack of satisfactory solutions for all parties and the industry's inherent secrecy.

Disagreements among the focus group regarding the best strategy suggest a lack of clear guidelines on sustainable water management. This study also highlights several shortcomings in water management, including inadequate community engagement, regulatory deficiencies, and a lack of trust in the mining industry. To address these issues, a holistic approach involving all stakeholders, participatory processes to establish agreements, government oversight to ensure regulatory compliance, and a transparent relationship-building approach are recommended. These actions aim to develop a more effective and sustainable water management system in northern Chile, integrating communities and stakeholders. Future research should gather quantitative data on water availability to assess community impact, improve data accessibility, and prioritize long-term water management practices, enhancing resilience against severe droughts in mining areas.

5.1. Future Work

Future research arising from this work, which extends beyond its current scope, should broaden its geographic scope to include other mining regions in Chile, comparing results to develop water management strategies applicable nationwide. Ensuring more inclusive participation by involving a wider range of stakeholders, including indigenous communities, small mining enterprises, and other affected sectors, will enhance the relevance of future research.

In terms of developing effective proposals for water management, incorporating more detailed quantitative analyses alongside qualitative findings will enhance the robustness of the research, including modelling and simulation studies of water resources to predict their impact. Longitudinal studies should be conducted to assess how perceptions and the effectiveness of water management strategies evolve over time, allowing for continuous adjustments and improvements. Further studies are also needed to quantify the economic and social impacts of the proposed water management strategies, providing a more solid foundation for policymaking.

Author Contributions: Review and editing, L.R.-B. and J.L.S.; writing, H.V.-G. and K.A.-C.; interview and survey: K.A.-C. and H.V.-G.; supervision, H.V.-G.; analysis of strategies, K.A.-C.; project administration, J.L.S. and L.R.-B. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: The original contributions presented in the study are included in the article, further inquiries can be directed to the corresponding author.

Acknowledgments: The authors want to express their particular thanks to the Faculty of Engineering at Universidad del Desarrollo for providing financial support for the publication of this paper.

Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A

Stage 1. Characterization and understanding of the reality

1. What do you understand by water resource management in this area? Who are the actors involved?
2. Making a distinction between industrial, freshwater, and consumable water: What is your opinion on the use of freshwater by the industry? Why?
3. Where does the problem come from, or what is the origin of the scarcity of drinking water in this area?

4. Which factors and key communities do you believe should be considered to ensure that the community's perception is taken into account by the mining industry when managing the water resource?
5. How does water resource management operate by all its actors, considering a holistic approach?

Stage 2. High impact proposals

6. Understanding what ecological flow is and what it implies: how can we modify the current situation of water resource use by the mining company to avoid affecting the ecological flow and surrounding communities?
7. Considering the scarcity and the use given to the water resource by different agents in this area, do you have any specific proposals for improving or changing the way the resource is managed, ideally in the short term and with high impact? What are they?
8. If a change strategy based on the establishment of feasible agreements between mining companies and communities in desert areas to manage the water resources was proposed, what would you think about such proposal?

Stage 3. Awareness of transformations

9. What, in your opinion, are the costs of implementing an organizational policy that takes communities into consideration to improve the perception of the mining industry?
10. What kind of threat or risk could a plan of agreements like the one described above pose to a mining company?
11. In your opinion, what are the factors that would facilitate and hinder the implementation of a process to improve the perception of the mining industry?
12. What would you recommend to manage these changes?
13. What would be your main concern regarding the application or implementation of this type of strategy?

Appendix B

Stage 1. Characterization and understanding of the reality

1. How would you rate the management of water resources in northern Chile?
   (a) Very good.
   (b) Good.
   (c) Neither good or bad.
   (d) Bad.
   (e) Very bad.
   (f) Prefer not to answer.
2. What do you think is the main cause of poor water management in the area is, considering all the agents that use the water?
   (a) Poor communication among the agents who use the resource.
   (b) Every agent is seeking their own interests.
   (c) Because mining operations should reduce their scale.
   (d) Prefer not to answer.
3. Which of the following factors or communities do you consider having the greatest impact on water management in the area?
   (a) Shareholders of mining companies.
   (b) Chilean government.
   (c) Farming communities.
   (d) Shareholders of local water management and distribution companies.
   (e) Prefer not to answer.

Stage 2. High impact proposals

4. What do you think is the best strategy to improve water resource management? Consider that ideally this strategy should have high impact and be short-term.

(a) To develop technology for sustainable and conscious use of the resource.
(b) To change regulations regarding water use.
(c) To invest in assets that optimize the resource (i.e., desalinization, tailings thickness, etc.).
(d) To reduce the magnitude of mining in the area.
(e) Prefer not to answer.

5. Do you think a strategy based on the implementation of feasible agreements between mining companies and communities to manage the water resource would be effective?
   (a) Yes, I think it would work.
   (b) It would work with conditions.
   (c) It would work, but it would take a lot of time.
   (d) No, it would not work.
   (e) Prefer not to answer.

Stage 3. Awareness about transformations

6. What do you think would be the main threat of implementing a plan like the one described above?
   (a) The unfeasibility of mining projects.
   (b) A lower availability of job opportunities.
   (c) Damage to the mining industry's image.
   (d) There are no threats as it is an opportunity for improvement.
   (e) Prefer not to answer.
7. What do you think would be the main difficulty in implementing a strategy like the one described above?
   (a) The secrecy of the mining industry.
   (b) The determination of the communities not to want mining operations in the area.
   (c) The lack of objectivity in the information provided by the mining industry.
   (d) The lack of a solution that satisfies both parties.
   (e) Prefer not to answer.
8. What do you think would be the main facilitator when implementing a strategy like the one described above?
   (a) To provide a detailed report of how the industry uses the resource.
   (b) Transparency of the industry towards communities.
   (c) A participative engagement strategy with communities.
   (d) To provide objective general information to the communities.
   (e) Prefer not to answer.

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