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Review

Impacts of Groundwater Management Policies in the Caplina Aquifer, Atacama Desert

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Abstract: Groundwater constitutes one of the main sources used to satisfy the water demands of the different users located in a basin. Current groundwater pumping rates in many cases exceed natural recharge, resulting in the overexploitation of aquifers and the deterioration of water quality. Consequently, many aquifer systems in the world have applied and adapted policies to manage the use of groundwater. In this article, we investigate the impacts of groundwater management policies on the Caplina aquifer located in the Atacama Desert, Peru. To evaluate these impacts, we review policies and regulations implemented during the last 40 years. Likewise, more than 25 scientific investigations that were carried out in this aquifer are reviewed and analyzed to understand its hydrodynamics and hydrochemistry, as well as the impact of climate change, among other aspects. The results, based on scientific evidence, show that the current and future conditions of the groundwater of the Caplina aquifer are not sustainable, and likewise, public policies are not effective for reversing this situation. This leads the aquifer system to a situation in which there is a quality degradation of the water, to a point that may be irreversible.

Keywords: Atacama Desert; water science; water resources law; groundwater; public politics

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Citation: Pino-Vargas, E.; Espinoza-Molina, J.; Chávarri-Velarde, E.; Quille-Mamani, J.; Ingol-Blanco, E. Impacts of Groundwater Management Policies in the Caplina Aquifer, Atacama Desert. *Water* **2023**, *15*, 2610. https://doi.org/10.3390/w15142610

Academic Editor: Adriana Bruggeman

Received: 27 June 2023
Revised: 8 July 2023
Accepted: 17 July 2023
Published: 18 July 2023

1. Introduction

In many parts of the world, groundwater is one of the main sources used to satisfy the water demands of the different users located within a water resources system. On the other hand, population growth, economic development, and climate change, among other factors, increase the need for greater water consumption, exacerbating conflicts between users and the overexploitation of aquifers. In this sense, different policies and regulations have been developed, applied, and adapted to carry out the correct management of groundwater; however, many of them have not been effective in achieving the sustainability of aquifers [1–3].

Furthermore, freshwater scarcity is increasingly perceived as a global systemic risk [4]; this scarcity of water puts food security at risk, adding to the poor quality of the resource that allows the prevalence of diarrheal diseases—conditions the population to suffer significant levels of malnutrition [5]. In transboundary arid regions, where water resources are scarce, an important aspect of water management is the principle of equitable and reasonable use. States that share watercourses must decide which uses of water are more important than others [6]; likewise, the main management tools applied for their protection must be identified [7]. The anticipated water-related impacts of climate change increase the need for tools and policies that support proactive efforts to address current and future water-related conflicts [8].

In recent decades, intensive agriculture and the overexploitation of water resources have caused groundwater salinization in transboundary aquifers [9,10]. In this sense, the remote sensing of vulnerability seems to be an efficient tool for the management of water resources [10], and the proposal for the management and geo-valorization of unconventional water processes helps to promote better use through the application of recharge and artificial groundwater [11]. These approaches serve as a baseline to improve decision-making in groundwater management.

Thus, unrestricted compliance with the water resources law is vital for proper water management; therefore, its sustainable use requires effective management [12]. Globally, law and policy are appropriately combined in water management in river basins [13]. Legal issues that affect the integration of measures applied in basins to manage water use focus on relevant areas, such as population use, energy, agriculture, and mining [14]. Across the hemisphere, a series of experimental policy reforms and creative counter-practices have established Latin America as a continental force in global water policy [15].

In water-rich Central American countries, the struggle is to ensure access to drinking water for many of its residents, in addition to problems of water distribution and quality, a prolonged drought creates pre-existing governance challenges to guarantee water needs in rural areas [16]. Latin America, with enormous water resources in many parts of the continent and scarcity in others, faces particular water dilemmas; having the two wettest ecosystems in the world and the driest deserts makes it very important to conceptualize the most resource vantage [15,17].

In South America, the Guarani Aquifer System is a transboundary aquifer shared by Argentina, Brazil, Paraguay, and Uruguay. It stands as one of the largest freshwater reserves in the world and is one of the few aquifers whose management is regulated by an international treaty [18]. In addition, Mexico and the United States have a historical relationship in the political distribution of their transboundary waters; transboundary aquifer systems are considered strategic reservoirs in the process of building water security on the border shared by both nations [19]. From a critical analysis that combines different approaches from hydrogeology, geography, and political science, such as the scientific concepts on groundwater used in planning, and Mexican laws between the years 1948 and 2018, it is affirmed that they affected the forms and mechanisms of control and distribution of water, which were developed by the political power of the State, and favored the economic development of certain areas of the national territory [19,20]. In general, many levels of reform are needed to bridge the gaps between scientific knowledge and policy, and identifying these gaps will be critical to overcoming legacy legal effects and moving toward a policy that better reflects scientific reality [21,22]. In addition, given the need for groundwater and drought management, evidence-based science must be incorporated into public policy [23].

Moreover, water, as a common resource, is threatened by the possibility of over-extraction that generates a negative economic impact, conflicts between users, and greater income inequality [24]. Peru is no stranger to this common situation, which occurs in many countries around the world. We face similar problems, especially when water transfer projects are proposed from the highlands to the coast, where the need for water is increasing—the largest population of the country is located on the coast, and this is where the greatest number of agricultural activities take place. Water security, justice, and the politics of water rights in Peru and Bolivia use top-down and bottom-up formalization strategies attempting to convert customary institutions of water use into law [15]. In Chile, no real public policies have been implemented that aim to respond to the need for the recognition of the ancestral possession of the waters of indigenous peoples [25].

At the head of the Atacama Desert, it must be taken into account that droughts are linked to the behavior of groundwater [23]. In the Atacama Desert, the landscape stands out due to the clear presence of elements of geomorphological heritage (great coastal cliffs, deep ravines, volcanic cones, meteoritic craters), as well as biological heritage (charismatic species such as the Condor and Taruka, native and endemic species) and cultural heritage (pictographs, bofedales, terraces, religious festivals, and churches) [26,27]. The Chilean water model imposed by its dictatorship in 1981 is known as radical, neoliberal water management; in the future, it seeks to distort the idea of the Atacama Desert as a hyper-arid space, rich in mineral resources [28]. In this region, concern about the depletion of groundwater and its degradation has generated the concept of sustainability as a policy instrument in various management codes and directives around the world [21].

Likewise, global climate change projections indicate negative impacts on hydrological systems, with significant changes in precipitation and temperature in many parts of the world, with special emphasis on the Atacama Desert [29–31]. In this sense, it is important to develop research projects aimed at identifying the characteristics of the exploitation regime related to public policies that order the balanced extraction of groundwater while considering external forces such as climate change, population growth, and increased irrigation demands, among others.

Unlike what happens at the head of the Atacama Desert, in the middle, the weather systems produce recharge to the aquifers in the Atacama Desert between 24.5 and 25.5° S. This was investigated using δ18O and δ2H data in groundwater and precipitation combined with remote sensing methods. These analyses demonstrated that an important source of moisture is the Pacific Ocean [32].

Specifically, the Caplina aquifer, located within the Atacama Desert, has pollution problems due to marine intrusion caused by the overexploitation of groundwater. Since the 1980s, the water balance has been negative, and the state has not been able to adequately manage the scarce water resources that are available despite the different policies and regulations that were provided at the time [33–35]. The governability and governance crisis in the use of groundwater in the Caplina coastal aquifer is an element that contributes to the depletion and deterioration of groundwater quality due to marine intrusion processes [36–39].

In addition, several technical and scientific studies have been carried out in the Caplina aquifer basin to assess hydrodynamics, water quality, overexploitation, water availability, and climate change, among other aspects [29,35,36,38–42]. However, these studies do not address in depth the effects of policies and regulations applied to groundwater management in the Caplina aquifer. Therefore, the main objective of this study is to evaluate the impact of groundwater management policies on the Caplina aquifer by reviewing management instruments, implemented policies, and evidence based on scientific research, thus contributing to providing knowledge about existing imbalances in groundwater management to improve decision-making.

The results, in combination with the review of management instruments and policies implemented in the Caplina aquifer, along with scientific research, will help us to answer research questions such as the following: What impacts do groundwater management policies have on the Caplina aquifer? How can scientific evidence contribute to explaining the effectiveness of public policies?

2. Study Area

The Caplina aquifer, located in the basin of the same name in southern Peru, is located in the Atacama Desert, Tacna region, and is characterized by a hyper-arid climate with little precipitation [40,41,43–45]. It is bordered to the west by the Sama Basin, while on the east, it borders the Concordia Basin, shared by Peruvian and Chilean territory, and the Lluta Basin, which belongs to Chilean territory (Figure 1). The administrative sub-divisions of the Tacna region are the National Water Authority, the Caplina Ocoña Administrative Authority, and the Caplina Locumba Local Authority.

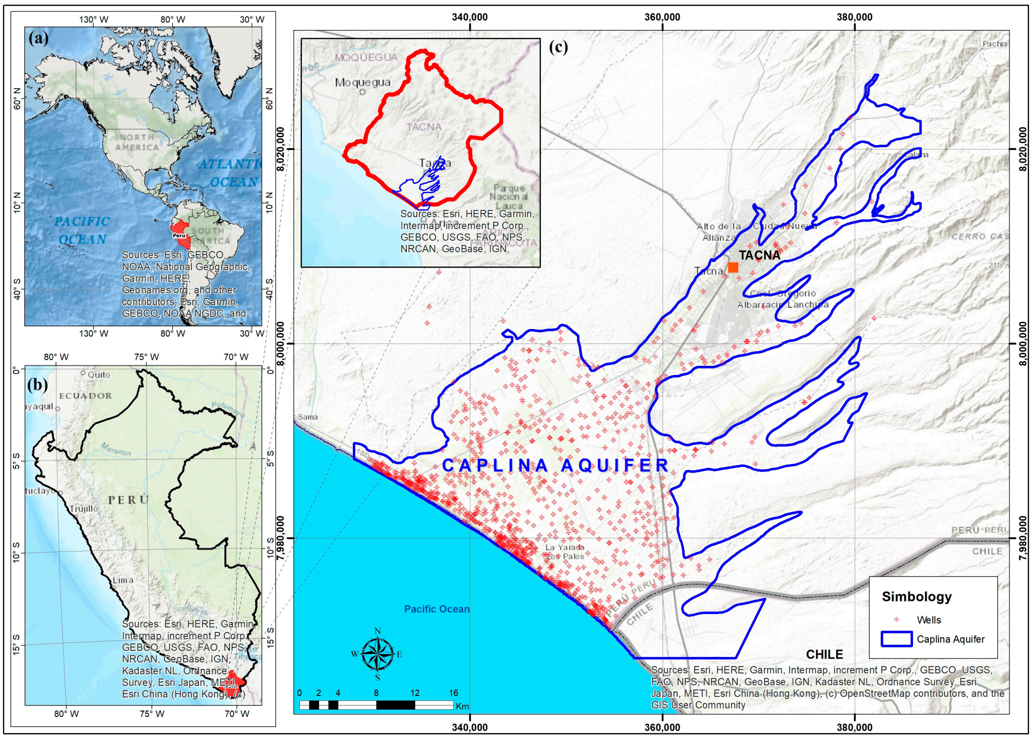

Figure 1. Location of the study area. (**a**) The Atacama Desert, (**b**) Caplina Aquifer, southern Peru, and (**c**) the Caplina aquifer in the Caplina basin.

The Caplina basin has two types of climate according to its location: a warm-temperate, desert-like climate with a moderate temperature range in the areas near the coast and a cold-moist climate in the high-elevation parts of the basin [30,46,47]. The preserved remains of fluvial activity constitute proof of the changing conditions of the limits, with this desert being a world witness of aridity [48,49].

The high Andean zone belongs to the central-western sector of the Altiplano, with a relatively low annual accumulated precipitation of 300 to 700 mm/year and very marked temporal variability, including wet periods from December to March and very dry periods from April to November [50–52]. The coastal zone has a desert climate, annual rainfall is scarce and even zero, the climate is temperate desert with moderate thermal amplitude, and the average annual maximum and minimum temperature (period 1950–2020) are 23.6 °C and 12.7 °C, respectively [38,40,45,50,53,54]. These climatic characteristics cause the region to present a water deficit—the demands for water for different uses are not covered [38,40,54], which has generated social conflicts over the use of surface and groundwater in the region.

The Caplina aquifer is mainly of Quaternary alluvial origin; it is a rectangular polygon with a flat bottom and steep and abrupt flanks. Downstream, the ejected cone of the Caplina River corresponds to a physiographic unit that begins in the Magollo stream and progressively widens downwards into a delta unit, reaching the beach line [31,35,43]. It is bounded from Calientes to the shoreline from northeast to southwest by rocky outcrops, with incipient wind cover and volcanic ash deposits [38].

Since the 1980s, the water level has decreased due to the overexploitation of groundwater; consequently, seawater intrusion into the aquifer has been recorded. In the coming years, the water level will continue to drop from 0.23 to 0.38 m/year, and saline intrusion will be five times greater (56–59 Hm^3/year), increasing the deterioration of the quality of the groundwater [31].

3. Materials and Methods

Historical information was collected from studies, reports, technical reports, and press releases, among other sources, and we carried out an analysis of the interrelationships between the main points of Peruvian legislation on water resources, the applications of water management actions, and the results of science. This study is a product of research projects developed in this region. We based our work on an integrated approach, looking for interactions between the elements to explain the response through internal and external interactions. The aim of this was to explore the application of the law in the context of the conclusions of the studies based on scientific evidence. The results of these interactions will allow us to conclude the sustainability of groundwater in the face of these approaches.

There is chronologically ordered documentation on the Caplina aquifer and in general on groundwater in the country. As an analysis technique, the method of legal hermeneutics was used, and the application of the regulations was compared in two jurisdictions of Peru, nationally, and in the Tacna region where the study area is located, specifically in the case of groundwater and analyzed international instruments. In turn, the analysis of these regulations in water matters was contrasted with the results evidenced by science, such as the results of developed research projects and the publication of scientific articles.

3.1. Peruvian Water Resources Law

On 31 March 2009, Law No. 29338, the Peruvian Water Resources Law, was published, consisting of 125 articles, 12 final complementary provisions, 2 temporary complementary provisions, and 1 repealing provision. This law regulates the use and management of water resources and includes surface, ground, and continental water and the assets associated with it. It extends to maritime and atmospheric water when applicable. Its purpose is to regulate the use and integrated management of water, the actions of the State and individuals in said management, as well as the assets associated with it.

This law has 11 basic principles, referring to: (1) Valuation and integrated management of water, (2) priority in access to water, (3) participation of the population and culture of water, (4) water security, (5) respect for the use of water by peasant and native communities, (6) sustainability, (7) decentralization of public water management and single authority, (8) precautionary, (9) efficiency, (10) participatory integrated management by river basin and (11) legal guardianship. These principles are established in the 125 articles of which the law and its regulations are made up.

3.2. Management Instruments

In the Caplina aquifer system of the 1980s, it was identified that the water balance was negative since the recharge was lower than the extraction. In this sense, a series of legal instruments were generated, aimed at conserving water in the aquifer, by the Ministry of Agriculture and Irrigation (MINAGRI), the Constitutional Court (TC) and Tacna Regional Government (GORE), the National Water Authority (ANA) and other government institutions (Table 1). In the period 1984 to 2010, the measures for the conservation and preservation of groundwater were given and ratified. In 2015, MINAGRI issued Supreme Decree No. 007-2015-MINAGRI, which is contradictory, indicating that "The areas declared closed maintain their condition, proceeding exceptionally and only once to formalize or regularize the licenses of water use in the Caplina aquifer". This contradictory management instrument collided with the water resources law; it stipulates that all water use licenses are granted when a surplus of water is demonstrated in the area in question.

Table 1. Groundwater management policies and regulations in the Caplina Aquifer.

Instrument	**Institution, Year, Scale of Application**	**Scopes**
Supreme Decree No. 080-84-AG	MINAGRI, 1984, Local	The underground waters of the La Yarada pampas were reserved for two years
Supreme Decree No. 020-87-AG	MINAGRI, 1987, Local	An extension is given for two more years for the groundwater reserve in the pampas of La Yarada
Ministerial Resolution N° 0555-89-AG/DGAS del	MINAGRI, 1989, Local	The execution of works intended to extract groundwater in the pampas of La Yarada is prohibited
Ministerial Resolution N° 696-98-AG	MINAGRI, 1998, Local	The ban is declared on the increase in the exploitation of groundwater in the aquifer
Constitutional Court ruling N° 1290–2002-AC/TC	TC, 2003, Local	It ruled on the declaration of closure and the non-application of regulations for the regularization of water licenses in the area declared closed
Regional Ordinance N° 009-2004-CR/ GOB.REG.TACNA	GORE, 2004, Local	Declared regional interest in the intangibility and conservation of groundwater and uncultivated land in the state of Las Pampas from La Yarada
Supreme Decree N° 065-2006-AG	MINAGRI, 2006, Local	The conservation and preservation of the water resources of the Caplina Valley are declared of public necessity and national interest, extending the ban to the entire Caplina aquifer
Water Resources Law, Law N° 29338	MINAGRI, 2009, National	Regulates the use and management of water resources and includes surface, underground, and continental water and the assets associated with it and extends to maritime and atmospheric water as applicable
Chief Resolution N° 327-2009-ANA	ANA, 2009, Local	The declaration of a ban on the aquifer of the Caplina River valley, which includes the La Yarada aquifer, is ratified; the prohibition of the execution of groundwater exploitation works
Regulation of the Law N° 29338	MINAGRI, 2010, National	The purpose of the Regulation is to regulate the use and management of water resources, as well as the actions of the State and individuals in said management, all by the provisions contained in the Water Resources Law, Law No. 29338
Chief Resolution N° 201-2010-ANA	ANA, 2010, Local	Ratifies the measures for the conservation and preservation of groundwater, based on the study "Numerical Modeling of the La Yarada Aquifer", which concludes that there is overexploitation of the aquifer and recommends maintaining the ban on the exploitation of the system
Supreme Decree N° 007-2015-MINAGRI	MINAGRI, 2015, National	The areas declared "closed season" maintain their condition, proceeding exceptionally and only once to formalize or regularize the water use licenses

3.3. Scientific Evidence Results

In recent years for the study area, research projects have been developed to specify the hydrogeological functioning of the aquifer system, the triggering elements of the problems between users, and the reasons for the occurrence of contamination processes by marine intrusion, among other aspects. In this sense, Table 2 shows a chronological list from 2017 to 2023 of scientific publications referring to the Caplina aquifer; the same ones that were used to contrast the approaches referred to public policies about the results of science.

Table 2. Articles published by research results of the Caplina aquifer, period 2017 to 2023.

Article	Journal, Year	Reference
A Multi-Criteria Decision-Making Technique Using Remote Sensors to Evaluate the Potential of Groundwater in the Arid Zone Basin of the Atacama Desert.	*Water*, 2023	[39]
Spatiotemporal Analysis of Urban Heat Islands about Urban Development, in the Vicinity of the Atacama Desert.	*Climate*, 2022	[55]
Sustainability of olive cultivation under a climatic approach in an arid region, head of the Atacama Desert.	*Ciencia y Tecnología Agropecuaria*, 2022	[53]
Deep Machine Learning for Forecasting Daily Potential Evapotranspiration in Arid Regions, Case: Atacama Desert Header.	*Agriculture*, 2022	[41]
Morphometric and Hydrogeochemical Weighting Methodology to Classify Susceptibility to Chemical Weathering in the Sub-basins of the Caplina River, Tacna, Peru.	*Tecnología y ciencias del agua*, 2022	[42]
Spatial and temporal evolution of olive cultivation due to pest attack, using remote sensing and satellite image processing.	*Scientia Agropecuaria*, 2022	[45]
Hydrogeochemical Characterization and Identification of Factors Influencing Groundwater Quality in Coastal Aquifers, Case: La Yarada, Tacna, Peru.	*Int. J. Environ. Res. Public Health*, 2022	[29]
Predicting adverse scenarios for a transboundary coastal aquifer system in the Atacama Desert (Peru/Chile).	*Science of The Total Environment*, 2022	[31]
Impacts of Climate Change and Variability on Precipitation and Maximum Flows in Devil's Creek, Tacna, Peru.	*Hydrology*, 2022	[40]
Evidence of climate change in the hyperarid region of the southern coast of Peru, head of the Atacama Desert.	*Tecnología y Ciencias Del Agua*, 2022	[54]
A benefit cost analysis of strategic and operational management options for water management in hyper-arid southern Peru.	*Agricultural Water Management*, 2022	[56]
The implementation of the ban as a tool to control the degradation of the La Yarada coastal aquifer, Tacna, Peru.	*Diálogo Andino*, 2021	[34]
Conflicts over the use of water in an arid region: Tacna Case, Peru.	*Diálogo Andino*, 2021	[38]
Hydrodynamics, Hydrochemistry, and Stable Isotope Geochemistry to Assess Temporal Behavior of Seawater Intrusion in the La Yarada Aquifer in the Vicinity of Atacama Desert, Tacna, Peru.	*Water*, 2021	[35]
Historical evolution of the hydrogeological conceptualization and use of the Caplina aquifer located on the northern edge of the Atacama Desert.	*Revista Ingeniería UC*, 2021	[57]
Overexploitation of groundwater and agro-export in the Yarada coastal aquifer, Tacna, Peru.	*Agricultura Sociedad Y Desarrollo*, 2021	[58]
Mitigation measures for the La Yarada coastal aquifer, an overexploited system in arid zones.	*Idesia*, 2020	[33]
Production of subterranean resources in the Atacama Desert: 19th and early 20th century mining/water extraction in The Taltal district, northern Chile	*Political Geography*, 2020	[28]
A benefit cost analysis of strategic and operational management options for water management in hyper-arid southern Peru	*Agricultural Water Management*, 2022	[59]
Factors that affect the depletion and contamination by marine intrusion in the coastal aquifer of La Yarada, Tacna, Peru.	*Tecnología y ciencias del agua*, 2019	[36]

Table 2. *Cont.*

Article	Journal, Year	Reference
The La Yarada coastal aquifer, after 100 years of exploitation as a livelihood for agriculture in arid zones: A historical review.	*Idesia*, 2019	[43]
Water security in the La Yarada coastal aquifer: Current and future challenges.	*Agroindustrial Science*, 2019	[60]
Future water availability in arid zone ecosystems in southern Peru and northern Chile.	*Agroindustrial Science*, 2019	[61]
Multidisciplinary study for the assessment of the geometry, boundaries, and preferential recharge zones of an overexploited aquifer in the Atacama Desert (Pampa del Tamarugal, Northern Chile)	*Journal of South American Earth Sciences*, 2018	[62]
Governance and governability crisis and its implications for the inappropriate use of groundwater, coastal aquifer case of La Yarada, Tacna, Peru.	*Idesia*, 2018	[35]
Hydrogeological characterization to determine the deterioration of water quality in the La Yarada Media aquifer.	*Journal of High Andean Research*, 2018	[63]
Effect of environmental and geological characteristics on water quality in the Caplina River basin, Tacna, Peru.	*Tecnología y ciencias del agua*, 2017	[64]

The findings, and the results of the research papers whose articles are shown in Table 2, can be classified into three well-defined groups: (1) Some articles report results on the characterization of climate variability and change in the study area. (2) The functioning of the aquifer system from hydrodynamics, hydrochemistry, hydrogeochemistry, and isotopy. (3) Management of the aquifer system, including governance and governability issues.

Recent studies show evidence of climate variability and change. At the head of the Atacama desert, the city of Tacna in Peru is among the largest arid cities with constant urban development, so it is necessary to understand the thermal pattern of the urban surface and its relationship with the availability of water [55]. Moreover, global projections of climate change indicate negative impacts on hydrological systems, and in many parts of the world floods and droughts are expected [40].

On the other hand, in recent years, in northern Chile and southern Peru, evidence of climate change has been detected in places where precipitation has never been recorded, and now there is an accumulation of water on the surface [65]. According to evidence found and recorded, this can be considered favorable or unfavorable for water availability [40]. In 2020, the hot spot detected by NOAA brought with it temperature anomalies between +4 and +6 °C, and had a high probability of being the agent causing atypical local precipitation in the study area [54].

Also, other studies present and analyze experiences from the tropical Andes based on a recent science-policy process on the national and supra-national government levels. During this process, a framework for the scientific contribution to climate adaptation was developed; it consists of three stages, including: (1) the framing and problem definition, (2) the scientific assessment of climate, impacts, vulnerabilities, and risks, and (3) the evaluation of adaptation options and their implementation. The study underlines the importance of joint problem framing among various scientific and non-scientific actors, the definition of socio-environmental systems, time frames, and a more intense interaction of social and physical climate and impact sciences [66].

The most relevant conclusions based on science for this region establish that groundwater has been overexploited. The period in which the exploitation was in a balanced regime (recharge—extractions) was until the 1970s, and after the 1980s, it has not been balanced [43,57]. Likewise, the crisis of governability and governance in the use of groundwater is an element that contributes to the depletion and deterioration of quality, due to marine intrusion processes [38]. Excessive pumping has now caused serious problems in groundwater management, including the abandonment of salinized water wells [29,33].

The Caplina aquifer system will continue to be unsustainable for the next 20 years, regardless of the exploitation scenarios that are imposed, and it is suggested that any mitigation measures require the participation of stakeholders [31]. Figure 2 shows the evolution of the water balance for the Caplina aquifer; this information has been generated by various institutions for the period 1965 to 2022. Table 3 shows the data collected and the institutions that report them: in 1965, the National Institute for Mining Research and Development (INIFM); in 1989, the Tacna Special Project (PET), attached to the National Development Institute (INADE); in 2009, the Geological, Mining, and Metallurgical Institute (INGEMMET); and in 2019 and 2022, the National Water Authority (ANA).

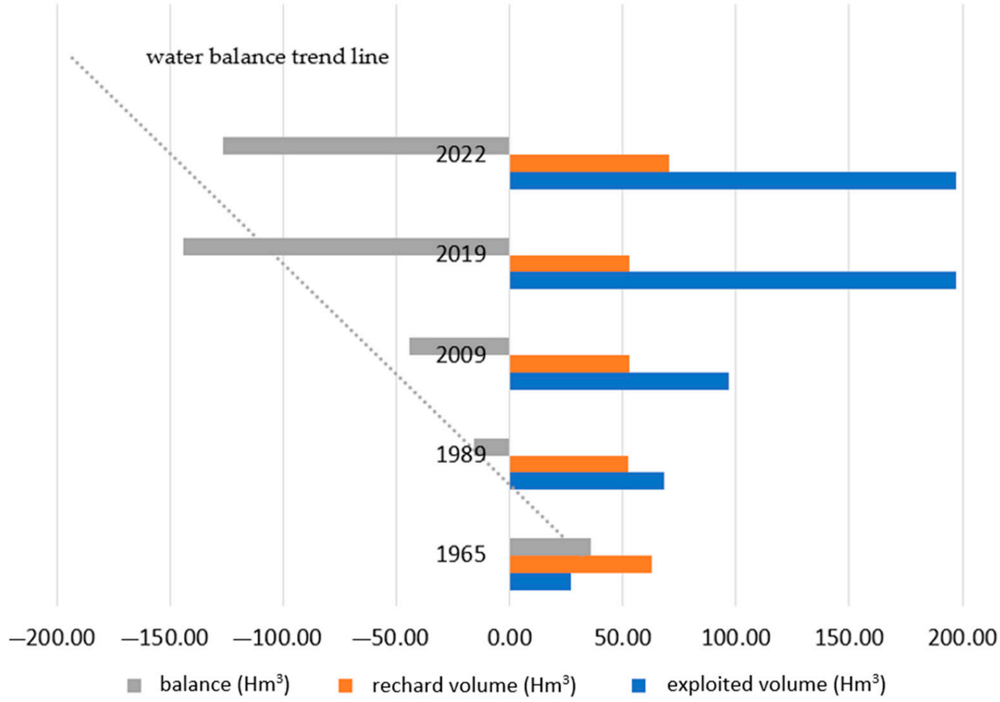

Figure 2. Trend of the water balance of the Caplina aquifer system period 1965 to 2022.

The conclusions obtained in these works minimize the possibilities of the sustainability of the Caplina aquifer system. The evidence supports that the water system and especially the underground in this region are compromised by processes of variability and climate change with negative impacts. The reserves are affected and the system is expected to collapse in the future, manifested in the salinization of groundwater exploitation wells. According to Figure 2, the trend of the balance line is geometric towards the negative position, with highly detrimental results regarding achieving sustainable groundwater management.

Table 3. Caplina aquifer water balance period 1965 to 2022.

Year	1965	1989	2009	2019	2022
exploited volume (Hm^3)	27.0	68.0	97.0	197.1	197.1
recharge volume (Hm^3)	63.0	52.5	53.0	53.0	70.6
balance (Hm^3)	36.0	−15.5	−44.0	−144.1	−126.5
institution	INIFM	PET-INADE	INGEMMET	ANA	ANA

3.4. Conflicting Users

According to the Peruvian water resources law, there are classes of water use established according to priority (primarily), population, and productive use. In the productive use of water, there are priorities established as follows: agrarian, livestock and agricultural, aquaculture and fishing, energy, industrial, medicinal, mining, recreational, tourism, and transportation. Conflicts of use in this region are established between (a) farmers and mining companies, (b) between state entities and high Andean community members, and (c) between state entities and groundwater users. These three cases are the ones with the greatest impact in the region.

In the first case, between farmers and mining companies, in the high Andean zone, farmers demand a review of the use licenses granted to formalized mining. This is further evidenced by a mining canon distribution policy that is granted to municipalities where the mine is located but not the municipalities where the water is used—a situation that has generated a series of claims and conflicts by users of the inter-Andean area of Candarave in the upper part of the Locumba basin.

In the high Andean zone, the conflict occurs between the government entities in charge of transferring water to the coast and the high Andean community members [34,38]. This represents a second case—the Peruvian state authorizes the execution of hydraulic water transfer projects that include surface and groundwater from the high Andean basins from the slope of Lake Titicaca to the Pacific slope, and the opposition of the community members is tenacious. They manage to paralyze the execution of the works that are being carried out, even when they have the respective authorizations and permits.

The third case corresponds to the use of groundwater from the Caplina aquifer, an overexploited aquifer. Overpumping has caused serious groundwater management problems, including the abandonment of saltwater wells due to marine intrusion; thus, the governance and governability crisis and its implications for the inappropriate use of groundwater are elements that contribute to the depletion and deterioration of groundwater quality, due to marine intrusion processes in the Caplina aquifer [36–38,43,53,54].

4. Results and Discussion

4.1. On the Instruments of Management and Public Policy

In Peru, the regulatory framework is in place, but the political will is lacking in its ability to generate the economic conditions and the mechanisms for cross-sectoral interaction and participation of strategic non-governmental actors to establish water governance [5]. These actions would make it possible to establish clear and precise guidelines on the Integrated Management of Hydrographic Basins (GIRH) in the basins of our country. The south of the country, located in a very arid region, has special characteristics—the water deficit is the main element to consider, which generates social conflicts among water users. This problem, in all its terms, alters and exceeds the laws regarding management regimes and limitations on the availability of water resources [37].

The Tacna region has a deficit of water resources, its demands for population use and agriculture, among other things, are not covered, and the gap is increasing over time. The surface water resources available from the Caplina, Sama, and Locumba rivers on the slope of the Pacific are insufficient. Regarding underground resources, these do not cover the current demand for La Yarada irrigation. The overexploitation of the Caplina aquifer, mainly for agriculture, since the 1980s has caused the depletion of groundwater and the intrusion of seawater [29,31,35,39,43].

As for the first case identified between farmers and mining companies in the high Andean zone, the fight for the use of water is permanent—the farmers demand a review of the water use licenses since the water resources law only establishes priorities for use. Agriculture, according to the law, has a higher priority; this problem transcends fields of the national economy and becomes very complex, and in this sense, we find legal loopholes that do not allow for resolving this type of conflict.

The conflict between the government entities in charge of transferring water to the coast and the community members of the high Andean zone dates back many years—to when the water deficit in the city and valley of Tacna began to show. The water resources law and its regulations do not endorse or guarantee the cover of water demands using water transfer between basins; legal actions have paralyzed the execution of works; and the situation has become uncertain, which seriously compromises the sustainability of groundwater in this region. The history of the world is full of tensions caused by the scarcity of natural resources such as gold, diamonds, and oil; however, water, which until now had not been considered a factor in conflict, due to climate change, has become the "blue gold" of this century [7].

Regarding the use of groundwater from the Caplina aquifer, unauthorized users extract water and generate an imbalance, leading to a chaotic situation. Extractions far exceed recharge; in this sense, authorities try to restore order in the extractions, and the situation becomes very complex—social problems arise that lead to verbal and physical aggression against the representative authority of the state in water matters. It is necessary to have a specific regulatory framework for groundwater that recognizes its particularity; the institutional framework in terms of Water Law must be consolidated and strengthened [37].

In summary, we identified four main reasons why the policies and regulations had no effects in maintaining the balance in the Caplina Aquifer: (a) despite the policies and regulations provided, irrigation users continued with groundwater extractions. These even increased significantly due to the expansion of the agricultural areas and the construction of new pumping wells by unregistered users; (b) lack of interest and the political decision of the authorities at the regional and national level to carry out correct monitoring of the application of the policies and regulations provided; (c) lack of management of the competent authority to collaborate with the different sectors involved in water management to implement the strategies and obtain sources of financing and consequently enforce policies and regulations; and (d) lack of interest from the competent authorities in involving the academy in solving the Caplina aquifer problem based on scientific research.

4.2. About the Results of Scientific Evidence

The results from the scientific point of view are discouraging. The balance of the Caplina aquifer system shows a very high tendency towards negative values, which is counterproductive to achieving the objective of the sustainable management of the underground system. The excessive pumping that has generated the salinization of wells due to marine intrusion processes, resulting from governance and governability problems, has generated the degradation of the groundwater quality of the Caplina aquifer [31,33–35].

These research results show that the aquifer system is going through salinization problems due to overexploitation [58,67]. Currently, it is estimated that the extraction volume is five times the recharge volume [31]; at this rate of extraction, the system presents a negative trend and its collapse is imminent, unless the corresponding corrective measures are taken.

The corrective measures of the salinization processes of the aquifer can be of two types: the first is non-structural and the second is structural [33]. The first aims at establishing a management plan and the reorganization of extractions—elements of great importance because as the volume of extraction cannot be specified, there is great resistance to being audited from non-formalized users.

Regarding the structural measures, we can subgroup them into conventional and unconventional. The former refers to the use of reservoirs and water transfer between basins. The possible unconventional measures to implement are reusing, recycling, and desalination.

The third group of special or alternative measures include the administration of the recharge of aquifers and palliative techniques, such as the reduction of runoff in forests and urban areas, traps for runoff, savings, efficient pipe networks, reduction of evaporation in reservoirs, etc. Of these possible measures to be implemented, the artificial recharge of the aquifer combined with the implementation of hydraulic barriers is feasible, and volumes of transferred water will be available in the medium and long term that can be used for this purpose. Likewise, we propose incorporating the criteria of environmental education, water culture, awareness, and dissemination, applied to the conservation of the aquifer. Investment in the efficient use technology and water conservation measures generates more favorable net benefit results than investment in water supply infrastructure [56].

4.3. Management, Public Policy, and Science Results

An in-depth analysis of the water crisis shows that most of the problems that have arisen have been caused by incorrect, unprofessional and hasty policies [68]. Likewise, in the Caplina aquifer system, it is evident that groundwater governance does not have a good position in terms of coherence and scope, and in turn this will not improve if the actors do not interfere in the policies and pay attention to local governance. Governance and governability problems are the main factors in the process of the deterioration of water quality due to marine intrusion [37,38].

For this reason, the full participation of the government, civil society and the various institutions and user organizations grouped in a space where the results of science are considered and made compatible with management instruments is required, to guarantee the sustainable use of groundwater. The world water crisis has become a very serious crisis and every day it has deepened and worsened, and future wars are likely to be over water [68].

Establishing synergy between the actors and based on scientific results, it will be possible to evaluate and establish the precise guidelines to determine a program for the rational use of water in the Caplina aquifer, which will lead to a gradual recovery of the aquifer, based on mitigation measures. The measures must incorporate the reduction of extraction volumes, water culture, and external sources to replace the water used or artificially recharge aquifers [33,38]. Worldwide, favorable mitigation measures have been identified for the conservation of aquifer systems, among which are physical and non-physical or management actions, leading to the avoidance of collapse and achieving recovery and conservation [33]. Therefore, it is possible to implement non-structural and structural measures. The first aim at establishing a management plan and ordering extractions and the second at using reservoirs and the transfer of water between basins, as well as the reuse, recycling and desalination of seawater for the artificial recharge of the aquifer.

In the Atacama Desert in northern Chile and southern Peru, economic and social development is based on the use of fossil groundwater, and groundwater extraction has increased significantly in the last 30 years [59]. In addition, the Tacna region does not have sufficient water supplies for the different users, whose water allocations come mainly from groundwater from the Caplina/Concordia transboundary aquifer (Peru and Chile) and from the water transfer from the Maure transboundary basin, which also includes Bolivia. In this sense, given the problems of the Caplina aquifer, we suggest that the development and management of water in this arid region should consider the interests of the users involved from the three countries to avoid potential international conflicts over water. Likewise, we suggest the creation of an international commission made up of Peru, Chile, and Bolivia, whose mission would be to provide solutions to the water problem in the Atacama Desert.

5. Conclusions

Based on the scientific evidence approach, the sustainability of groundwater at the head of the Atacama Desert is seriously compromised. The current exploitation regime foresees an increase in marine intrusion and a deterioration of water quality; the imbalance is increasing, and groundwater managers in this region and the country do not react favorably to this situation.

From the approach based on public policies, water governance problems persist–these have generated significant drops in the groundwater levels, which has caused the intrusion of seawater, and the wells close to the beach line have been salinized. The state has generated a collision in the management instruments: on the one hand are closed seasons and on the other is a supreme decree to regularize licenses for the use of groundwater in an unbalanced system.

The results based on scientific evidence indicate the current and future conditions of this aquifer system. They denote the unsustainability of groundwater and that public policies are not effective enough to reverse this situation, leading to the groundwater quality degradation of the aquifer system to a point that may be irreversible.

In this cross-border aquifer system, with conflicts of use and with evidence of positive and negative climate change regarding water availability, sustainable management criteria must be established based on an ordering of extractions and policies should be set that lead to a controlled recovery-oriented exploitation program. Complementary programs can be established to incorporate additional water resources into the aquifer to stop its deterioration and start its recovery process, based on the integration of interrelated actions between the science-based evidence and the application of government public policies.

Author Contributions: Conceptualization, E.P.-V., J.E.-M., E.C.-V., J.Q.-M. and E.I.-B.; validation, E.P.-V., J.Q.-M. and J.E.-M.; formal analysis, E.P.-V., J.E.-M., E.C.-V., J.Q.-M. and E.I.-B.; writing—original draft preparation, E.P.-V., J.Q.-M. and J.E.-M.; writing—review and editing, E.P.-V., J.E.-M., E.C.-V., J.Q.-M. and E.I.-B.; project administration, E.P.-V. All authors have read and agreed to the published version of the manuscript.

Funding: Jorge Basadre Grohmann National University funded this research, and the research vice-rectorate funded the APC.

Data Availability Statement: Not applicable.

Acknowledgments: Funds financed this work from the mining royalties, IGIN, VIIN of the UNJBG, within the research project "Study of Hydraulic Recharge and Salinization Processes in the Caplina Aquifer, Tacna, Peru, for a Sustainable Management of Groundwater".

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

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