Improving Groundwater Governance in the Catalan River Basin District: Using and restoring aquifers to increase drought resilience

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Abstract

In the Mediterranean region, including Catalonia (NE Spain), droughts appear to be becoming more frequent and severe due to the enhanced variability in precipitation associated with climate change. Overcoming the challenges posed by severe droughts and ensuring more reliable water availability may require improving the management of aquifers, since these natural groundwater reservoirs could considerably enhance the storage capabilities in Catalonia but have been mostly ignored so far. This research explores this possibility by conducting semi-structured interviews with key stakeholders involved in water governance in the Catalan River Basin District. The findings uncover the main barriers hindering the use and restoration of groundwater bodies and ways to overcome them. Further analysis using a framework of "good water governance" enables the formulation of specific recommendations to improve groundwater governance. Namely, including deep aquifers under water regulations, continuing their research while educating policymakers and the population, and embedding water governance within every other sector plans to obtain a more sustainable management of this valuable resource.

Keywords: aquifers, groundwater, water governance, drought resilience, Catalonia.

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Table of contents

Introduction

The current research project started during the peak of the historical drought that Catalonia (NE Spain) suffered with exceptional severity from October 2023 until May 2024. However, as the saying goes, the first thing that rain washes away is the memory of the drought, and now this issue has left the headlines of the main Catalan communication channels.

Despite droughts being common in this Mediterranean region, the exacerbation caused by climate change has made the territory reach levels of water scarcity never registered before. While temperatures rise and rain patterns become more variable, Catalonia must adapt.

The path to achieving the goal of adaptation, drought resilience, is not straightforward. It is as complex as water management and as comprehensive as the water cycle. It requires a holistic approach to the problem and combining diverse solutions. Given the current socio-political context of Catalonia and the latest water management plans approved by the Catalan Government, aquifers (i.e., natural subsurface reservoirs) are considered to have untapped potential.

This research aims to uncover the reasons why aquifers have not yet been leveraged to mitigate the effects of frequent droughts and the increased interannual variability in precipitation in Catalonia. Furthermore, answering the question of *how to improve groundwater governance in the Catalan River Basin District to increase drought resilience.*

This thesis is structured in six main sections, starting with the present *Introduction,* Section I. Section II, *Background*, presents the information necessary to understand the reasoning leading to the research question and the context of the study. Section III, *Methodology*, explains the qualitative research methods employed. Section IV, *Results*, summarises the findings of the conducted interviews. These are then analysed in Section V, *Discussion*, using a theoretical framework of good water governance and policy recommendations are provided. Finally, Section VI, *Conclusion*, revisits the main outcomes of the research.

Background

This section clarifies how improved governance of groundwater in the Catalan River Basin District (DCFC, for its acronym in Catalan) could increase drought resilience in the region. To do so, it mainly provides context for the problem addressed, a summary of the water management system (WMS), and justifies the choice of aquifers as a potential solution, so far overlooked.

Climate context: Droughts

Episodes of meteorological drought are inherent to the Mediterranean climate (Essa et al., 2023), but Catalonia has experienced two record-breaking droughts in the past 20 years (Mira, 2023). The latest one started in the autumn of 2020 and is still ongoing more than three years later (Generalitat de Catalunya, 2023). Additionally to its exceptional duration, its unprecedented intensity and wide geographical reach make it the most severe drought in the region's history (Generalitat de Catalunya, 2023). According to the definitions of drought introduced by Wilhite and Glantz (1985), the current episode of meteorological drought in Catalonia has also reached its worst possible stage, having altogether agricultural, hydrological, and socioeconomic impacts. The lack of precipitation not only affects human activities but has also reached the extent of being detrimental to the ecosystems (Crausbay et al., 2017; Acció Climàtica, Alimentació i Agenda Rural & Presidència, 2024), which makes it a pressing topic and motivates this research project.

As a result of climate change, drought is predicted to increase both in intensity and frequency in the Catalan territory (Barella-Ortiz & Quintana-Seguí, 2019). In order to effectively reply to the inherent call for adaptation policies, the nature of these droughts must be understood. The mainstream discourse is that less rainfall is the root of this problem (see, for example, the last water-saving campaigns of the Catalan Government: *Estalvi i eficiència de l'aigua*, 2023 & 2022). However, reality is far more complex. In fact, climate studies in the region

have not identified a clear decreasing trend in precipitation – except during summer –, but a clear increase in precipitation variability (Barella-Ortiz & Quintana-Seguí, 2019), expected to continue rising in the future (ACA, 2022). Therefore, these predictions jeopardise water availability in temporal rather than quantitative terms.

The goal: Drought resilience

Long-term thinking is a fundamental component of resilience for climate change adaptation planning. Concretely, in a scenario of variable resource availability, resilience means diversification of sources (Kim et al., 2020) and storage capacity (Dillon et al., 2018). If the natural supply is intermittent, but the demand is rather constant and predictable, one must be able to store the surplus to supply it when needed (Dillon et al., 2018). In the case of the Catalan government, the ability to increase the region's resilience against future droughts depends on its water storage capacity to tackle the rising variability in precipitation.

Water consumption patterns

During the historical drought of 2008, the inhabitants of Catalonia adopted many water-conservation behaviours (Vallès-Casas et al., 2017). Those new consumption patterns became established thanks to multiple awareness-raising campaigns; and even strengthened due to the widespread of small technological upgrades at the domestic level; the implementation of new water tariffs; and the increased efficiency in water production systems and distribution webs (ACA, 2022a). The most tangible result was a significant drop of 5% in annual household consumption between 2007 and 2021, despite the 8% growth in population (ACA, 2022a). Currently, Barcelonians consume on average 102.85 litres of water per person a day (ACA, 2023), one of the lowest values worldwide compared to similar cities in socioeconomic terms (Together for Water, n.d.).

Nonetheless, water consumption in Catalonia is well beyond the amounts that the local hydrologic system offers (ACA, 2022b). Only worryingly low quantities (between ¼ and ⅕) of the

water needed to maintain the current lifestyle in Catalonia come from resources captured within the Catalan territory (ACA, 2022b), and an overwhelming amount is imported in the form of virtual water embedded in products. The present paper will not address this overarching issue due to the scope constraints of a Bachelor's thesis. Instead, it will focus on presenting aquifers as a tool with the potential to contribute to the intricate Catalan landscape of water and drought governance by adding storage capacity to mitigate the consequences of precipitation variability.

Legal framework: Water legislation in Catalonia

The Catalan River Basin District (DCFC)

The Catalan water scheme is legally bound by Spanish and, by extension, European regulations. The Catalan Government only has complete water jurisdiction power in the Catalan River Basin District, which was delimited in 2009 and recently updated in the Decret 28/2022 (see red area in Figure 1). The rest is part of the Hydrographic Confederation of the Ebro River (CHE, for its acronym in Catalan) and is regulated by the central Spanish Government (see grey area in Figure 1). The DCFC extends over half of the Catalan territory and comprises the basins of those rivers which have both their headwater and mouth within the Autonomous Community of Catalonia, as well as the related coastal and groundwater resources.

Besides being regulated by different governments, these two halves of Catalonia are socio-economically very different, as Figure 1 also illustrates. Due to the high levels of urbanisation and concentration of population by the coast, domestic and industrial uses are the predominant water consumers in the DCFC.

Figure 1

Distribution of water consumption in Catalonia, in relation to its territory and population

Note. Adopted from Agència Catalana de l'Aigua (2022a). Own translation from Catalan to English.

The European Water Framework

After the approval of the European Water Framework by the Directive 2000/60/CE establishing a framework for Community action in the field of water policy, the Catalan Water Agency (ACA, for its acronym in Catalan) was founded. According to this new European vision, it became the Catalan Government's organism dedicated to planning and executing water management in the DCFC (*Sobre L'ACA*, n.d.).

Since the entry into force of the Directive 2000/60/CE, all European member states must submit water management plans every six years. Subsequently, at the regional level, the ACA has so far designed three cycles of these plans for the DCFC (ACA, 2009; ACA, 2016; ACA, 2022b). They build up on each other and maintain a very integral approach to water management. The last one, for the period 2022-2027, proposes a series of measures requiring an investment of 2,400 million euros (ACA, 2022c). They address a wide range of issues, from general social needs, such as more public participation in water management, to highly

technical and specific actions, like the reduction of nitrates from agricultural origin (ACA, 2022c). It is observable that an important part of the measures are essentially technological, such as the construction of desalination and wastewater treatment plants, the renovation of supply infrastructure, or the erection of a physical barrier to avoid saltwater intrusions in a key coastal aquifer. On the other hand, many robust nature-based solutions, such as the rehabilitation of rivers or forest management to recover blue water, are put forward too.

Drought-related regulations

Spain is praised for having one of the longest records of water legislation in the EU and having shifted toward a rather proactive drought risk reduction approach through local Drought Management Plans (Ortiz et al., 2021). In January 2020, the Catalan Government, through Acord GOV/1/2020, approved the creation of a special action plan to face scenarios of drought alert and eventual drought. Known as the “Special Drought Plan”, it is a novel water management tool of both preventive and responsive nature (Generalitat de Catalunya, 2020). Much of its effectiveness lies in the production of six colour-coded drought scenarios (ranging from blue meaning normality, to red as emergency) which are determined by concrete indicators and include detailed steps to follow, easing the communication of the regulations to the general public (ACA, 2020).

A partial solution: Aquifers

What are aquifers?

The European Environment Agency (2017) defines an aquifer as a “subsurface layer or layers of rock or other geological strata of sufficient porosity and permeability to allow either a significant flow of groundwater or the abstraction of significant quantities of groundwater” or, similarly, as “layers of rock, sand or gravel that can absorb water and allow it to flow”. Moreover, the organisation points out the ability of aquifers to act as groundwater reservoirs when located

on top of impermeable rock in the same glossary entry; and warns of their vulnerability in front of contamination and saltwater intrusions.

Aquifers are very relevant when it comes to water management because they represent the biggest bodies of liquid freshwater on Earth. Of all water on the planet, only 2.5% is considered freshwater; almost 70% of this already small quantity, is locked up in its solid state in glaciers and ice caps, 30% is available as groundwater resources, and the remaining 1.2% exist in the surface and other forms (Shiklomanov, 1993).

When it comes to policy making, and for the purpose of this research, the terms aquifers and groundwater (i.e., container and content) are used interchangeably. This is the case because only the groundwater stored in aquifers is really accessible to humans and hence available for management.

Why aquifers?

As previously mentioned, the DCFC, and Catalonia as a whole, face the big challenge of adapting to the increasing precipitation variability in order to increase the territory's resilience to future droughts. Having analysed the current holistic plans of the main water management institutions in the region, the present study aims to uncover the reasons why aquifers have not yet been leveraged to mitigate the effects of frequent droughts and the increased interannual variability in precipitation in Catalonia.

The use of aquifers can be a partial measure to improve water availability at all times. This possibility requires (a) increasing visibility and use of already available groundwater resources, and (b) restoring quantitatively and chemically the overexploited and polluted aquifers to add available water resources.

For this research, the nature-based strategy of using and restoring aquifers was chosen as a more sustainable alternative to the popular technological approaches. The latter pollute as a side-effect (Einav et al., 2003) and were therefore considered counterproductive as a predominant path to climate change adaptation. Moreover, the latest water management plan

(2022-2027) also suggests using more groundwater resources in the long term. It is considered that they are mostly available in great quantities (ACA, 2022b), but seems to forget their lack of quality.

Regardless of the statement that "current measures and technologies allow the utilisation of practically all resources affected by water quality problems" (ACA, 2022b), we believe that a complete restoration of the ecosystem services of aquifers is a longer-lasting solution full of potential to add source diversity and therefore increase resilience (Kim et al., 2020).

Theoretical Background

Since the 1980s, Integrated Water Resources Management (IWRM), defined as “a process which promotes the co-ordinated development and management of water, land and related resources, in order to maximise the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems” (Global Water Partnership, 2000) has been considered imperative for good water management (Hofstra, 2013).

In the last decades, a new concept has emerged as a concrete means to put this theoretical principle of IWRM into practice (Havekes et al., 2016). This is the idea of Water Governance, which refers to the “range of political, social, economic and administrative systems that are in place to develop and manage water resources, and the delivery of water services, at different levels of society” (Rogers & Hall, 2003).

Good Water Governance

Subsequently, there has been a proliferation of water governance frameworks explaining how this could look in more detail (Havekes et al., 2016). Herman Havekes and other researchers evaluated the most significant frameworks and developed a comprehensive new one, which they called the Three-Layer Model of Water Governance (2016). The Three-Layer

Model is meant to be a straightforward tool employed to make both a quick assessment or start a deep evaluation of any system of water governance (Havekes et al., 2016). In a very straightforward fashion, every element of each layer (see Figure 2) can be approached with the questions: what *do we have that works, what is missing,* and *how can water governance be improved*?

Figure 2

Three-Layer Model of Water Governance

Content layer	Clear policy
	Knowledge and skills
	Information
Institutional layer	Organisation
	Legislation
	Financing
Relational layer	Culture and ethics
	Communication and cooperation
	Participation

Note. Own work based on Havekes et al. (2016).

Methodology and Methods

Research question and aims

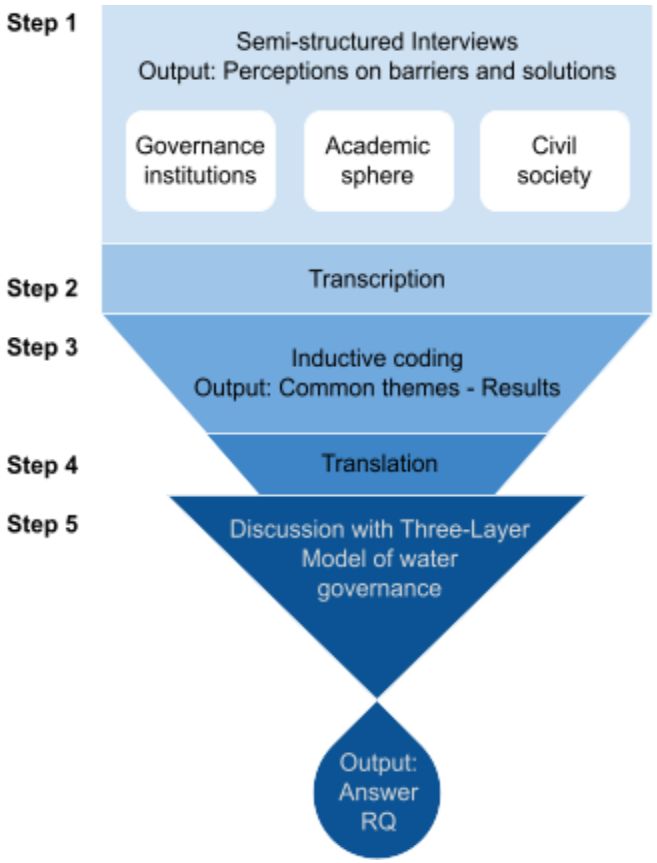
For all the reasons explained above, this thesis addresses the research question: *How to improve groundwater governance in the Catalan River Basin District to increase drought resilience?* Consequently, the aims are to uncover the barriers to using and restoring aquifers in the DCFC and to prescribe concrete measures to improve the situation.

Study Design

In order to answer it, one must first comprehend the WMS in the DCFC and establish the relationship between better groundwater governance and increased drought resilience. Both of these requirements were fulfilled in the literature presented in the *Background* section. Second, it is necessary to identify the barriers to using and restoring aquifers in this context, and how to overcome them. This knowledge was gathered by conducting interviews with key stakeholders involved in water management in the studied region. Lastly, the findings were discussed through the lenses of the Three-Layer Model of Water Governance, which allows for a detailed analysis of the current system and to identify its shortcomings.

Figure 3

Step-by-step visual representation of the research methods used



Note. Own work.

Participants

The participants of this research were selected to represent the three key types of stakeholders involved in water governance in Catalonia: (a) Policymaking, or governmental organisations; (b) Knowledge production, or academia; and (c) Civil society, or non-governmental organisations. This choice was made to portray the diverse range of existing opinions.

In the first group, three representatives from two main organisations at the regional and local level were interviewed. One from the ACA, as previously mentioned, the most important public institution in the Catalan water sector; and two from the Costa Brava and Girona Water Consortium, which operates at the local level with 47 municipalities (CACBGI, 2024). The second group (Knowledge production or academia) was composed of a professor from the Technical University of Catalonia specialist in aquifers; and a researcher from the Ecological and Forestry Applications Research Centre involved in drought-related studies. Lastly, the civil society opinion was gathered from the local association “Group to Defend the Ter”, formed by citizens worried about the conservation of the river Ter (GDT, 2024); and the organisation “Coordinator for the Safeguard of the Montseny" which fights many issues related to the nature reserve of the Montseny mountain range, including water management (CSM, 2024). Additionally, a member of the Water Observatory of Terrassa was interviewed, being an advisory body mid-way between the governance sphere and the civil society because it started as a citizens’ initiative to request public management of water, later institutionalised within the municipality (OAT, 2024).

Table 1

Summary of participants' main characteristics and identifying label assigned

Label	Sphere	Institution/Organisation (acronym in Catalan)
PG1	Governmental (regional)	Catalan Water Agency (ACA)
PG2	Governmental (local)	Costa Brava and Girona Water Consortium (CACBGI)
PG3	Governmental (local)	Costa Brava and Girona Water Consortium (CACBGI)
PA1	Academia	Technical University of Catalonia (UPC)
PA2	Academia	Ecological and Forestry Applications Research Centre (CREAF)
PS1	Civil Society	Group to Defend the Ter (GDT)
PS2	Civil Society	Coordinator for the Safeguard of the Montseny (CSM)
PSG	Civil Society/Governmental	Water Observatory of Terrassa (OAT)

Note. Own work.

Data Collection

This study used qualitative research methods, concretely conducting semi-structured interviews with representatives of the aforementioned institutions and organisations. See Appendix A to find the set of fixed questions asked to all interviewees, as well as examples of interviewee-specific questions prepared beforehand or improvised spontaneously during the interviews. Interviews were conducted until data saturation was reached, that is when two interviews in a row did not provide any new insights into the researched topic but only new ways of phrasing the same ideas mentioned by previous interviewees. This resulted in a total of eight interviews, with interviewees from seven organisations. Ranging from 40 to 60 minutes long, they were held online using the free video-calling platforms *Google Meets* and *Teams.* Simultaneously, the audio was recorded using the *Voice Memos* app, always with the previously signed consent of the participants. The language of the interviews was Catalan, for being the

native language of both the interviewer and most of the interviewees, who otherwise speak it proficiently as required to work within the public sector of Catalonia. Nonetheless, Spanish and English terms, mostly technical (e.g. MAR), were sometimes used and understood by all parties.

Data Analysis

The interview recordings were transcribed using the online artificial-intelligence-powered transcription software *Sonix.ai.* Afterwards, they were coded using the academic tool *Atlas.ti.* In order to maintain the process as truthful to what the participants wanted to communicate, inductive coding was used. This meant that the codes emerged from the interviewees' words and the codebook kept growing and developing until the end of the coding process, instead of being elaborated beforehand and imposed on the transcripts later. Common themes were later extracted from the codes obtained and used to answer the different research sub-questions. Furthermore, to avoid translation bias (e.g. misinterpretation of connotations) the coding was done with the original transcripts in Catalan. Only later on, the quotes selected to be cited in the main text were translated into English by the researcher herself to make sure that the message was accurately conveyed. Lastly, the findings were analysed through the lenses of the Three-Layer Model of Water Governance by Havekes et al. (2016) in order to provide sound recommendations.

Ethical Considerations

This research received ethical approval from the Ethics Committee from Campus Fryslân, University of Groningen. The discussion of water management was not considered a topic involving enough personal content to put the participants in a vulnerable position. Nevertheless, all interviewees were asked to read and sign an Informed Consent Form (see Appendix B) before conducting the interview. In order to prevent any kind of deception, the informative form also included clear information about the goals and nature of the research and

the absence of direct benefits of participation. Lastly, the data gathered was stored and treated according to the General Data Protection Regulation of the University of Groningen.

Results

The following sections present the findings of the interviews with the key stakeholders involved in water governance in the DCFC, mainly regarding the use and restoration of aquifers. These are broadly divided in two – *Barriers* and *Solutions* – and further sub-structured according to the themes identified during the coding process.

Common ground

In all cases except for one, interviewees said that the current WMS in Catalonia is good but added that it definitely has room for improvement to a bigger or smaller degree. Its intrinsic value was even praised by PA2, who pointed out that many other world regions do not even have something similar. The deviating opinion, namely from the stakeholder of the ACA, was that water management was already being done as good as possible. They claimed that if certain actions are not being taken, it is because it is unfeasible economically or technically.

Similarly, the majority of participants indicated that aquifers, and generally groundwater, are still forgotten in policy-making, while the representative of ACA in this research was the only one disagreeing. They conceived this as a misperception caused by the fact that it is impossible to predict aquifers' pollution episodes, and therefore to plan their qualitative restoration in detail. This would translate into fewer pages in the water management plans addressing this unpredictable problem and, hence, a false perception that it is underestimated. The participant from the other governmental organisation interviewed, the CACBGI, remained neutral since they perceived aquifers' visibility as being dependent on their relevance in each area, rather than being (miss)portrayed the same way across all the territory or management plans.

Fortunately, in line with the literature reviewed and the assumptions at the base of this research project, all interviewees agreed that the use and restoration of aquifers in the DCFC can play a role in drought resilience, and ultimately in climate change adaptation.

Barriers

The main barriers hindering the *use* of aquifers (i.e. groundwater) and/or their *restoration*, mentioned by the interviewees, are of four different kinds: economic, technical, legal, and socio-political.

Economic limitations

Firstly, there is the reality that *use* of surface water is simply cheaper than groundwater because it is more accessible (PG3, PA1). Nevertheless, according to the participants of this research, most economic barriers are related to the costs of *restoring* aquifers. Concretely (a) quantitatively restoring overexploited aquifers, (b) qualitatively restoring polluted aquifers, and (c) prevention in counterposition to restoration.

Nowadays, quantitative restoration refers to Managed Aquifer Recharge. Commonly known as MAR, these are a wide set of techniques used to purposefully recharge aquifers for environmental conservation reasons or to subsequently recover the introduced water (NGWA, 2023). More often than not, these techniques require building large infrastructures, which makes it expensive. However, as PA1 clearly explained, the costs vary depending on the characteristics of the aquifer and the resulting complexity of each MAR project. The deepness underground at which an aquifer is located is among the factors with the biggest impact, namely superficial aquifers are easier to fill up than deep ones (PA1).

The interviewees also enumerated factors that shape the costs of qualitative restoration interventions on polluted aquifers. PG1 pointed at the scale of the pollution incident, as well as the concentration and type of chemicals involved – e.g. (in)organic, (in)soluble, degradable in (an)aerobic environment. The restoration technique used also influences the total costs, being

in-situ approaches cheaper than ex-situ ones. PA1 shared that ex-situ chemical restoration requires extracting the groundwater and treating it in another location, which increases the costs so much that it is mostly regarded as an economically inviable option. On the other hand, PG1 indicated that the economic feasibility of in-situ treatments often depends on a combination of the size of the polluted water body and the strategic importance of the aquifer. This means that very costly interventions in aquifers without a defined community of users associated may be deemed economically unworthy to restore (PG1).

Besides the costs of restoration themselves, PG1 goes on to say that the accountability to pay for the restoration poses another economic barrier. “Who should restore groundwater? Whoever caused the pollution. This is what the law says, what common sense says, what European regulations say” (PG1). Unfortunately, according to them, in practice this is much less straightforward. They explained that if the contamination happened decades ago, when the regulations on waste management were more lenient, it is often necessary to spend resources on making a historical search to trace back the polluter (PG1). Yet, sometimes it is impossible to point at specific agent(s) when there were multiple industries working in the same area (PG1); or farmers fertilising neighbouring land lots (PA2). However, PG1 adds that even when concrete polluter(s) are identified, they may not exist anymore or have the economic capacity to pay for the restoration, leaving the ACA to cover the tens of millions of euros in costs. Given the limited amount of money available, and its public nature, the administration has to assess whether the costs of restoring certain aquifers are worth it (PG1).

PA1 also raised the concern that, although big organisations have to make an investment to cover the initial costs of restoration projects, the consumers of this water will be the ones eventually paying them back. Therefore, the more expensive the project, the more the consumers’ water bill will increase. While everyone is aware that this will inevitably occur in the scenario of climate change and more frequent droughts, not everyone will be able to afford these prices (PA1). There exists a clear and strong divide between urbanites and farmers

regarding the effects of water prices, because agriculture needs plenty of water and paying each cubic litre for irrigation at 2-3€ is simply unreasonable (PA1).

Regarding prevention, as a more sustainable alternative to restoration, the majority of interviewees declared that avoiding pollution or over extraction in the first place would be cheaper than restoring the already damaged aquifers (PG1, PS1, PA2). Nonetheless, there was a remarkable exception from PA1, who thought the opposite, that prevention is more expensive than restoration. This academic clarified that compensating the meat industry to stop pouring pig slurry on the ground would cost more than the chemical restoration projects of the polluted aquifers underneath.

Technical constraints

The technical constraints identified by the interviewees influence both the *restoration* and *use* of aquifers. PG1 claimed that despite the huge impact they have on the feasibility of a project, these barriers are often overlooked.

Technical constraints were often mentioned hand in hand with economic limitations – the more complex the technical part of a project is, the more expensive it becomes. Because of all the economic costs of *restoring* aquifers described above, pilot testing is a common practice before making major investments to scale up (PA1). As PG1 pointed out, this is especially important because, unlike dams, aquifers are not perfectly defined tridimensional bodies of water, and therefore it is very difficult to know the exact quantity of water they contain.

Among all the technical constraints that a project of quantitative restoration could encounter, the deepness at which the aquifer is located seems to be the most determinant one. As previously mentioned, the infrastructure needed to conduct MAR on a superficial aquifer is much less than that required to inject water into a deep aquifer. Instead, in qualitative restoration projects, the physicochemical composition of the aquifer and the pollutant are the most relevant factors determining the success of the intervention. For example, whether the aquifer is of porous or fractured rock, the amount of different pollutants and their solubility, or their

concentration. Moreover, particularly for ex-situ restorations, the unavailability of a container where to store massive quantities of water during the restoration treatment often makes this practice technically impossible.

The participants suggested that the technical constraints of *using* groundwater are related to a lack of understanding of this source. PA2 holds that the current scarcity of local knowledge stems from the historical abundance of surface water. Still, even when they are somewhat understood, the fact that they are unseeable, hard to access, and heterogeneous (PG1), makes it very difficult to generalise or draw conclusions, in comparison with gaining knowledge about rivers (PA1). Lastly, because of the same reasons, their study is *very* complex even for the experts (PA2). Therefore, data production, with piezometric measurements, and monitoring, is essential to understanding the behaviour of such bodies of water (PG2).

Legal conditions

Legal affairs can also hinder the execution of projects to *use* and *restore* aquifers. The national Law of Mines, mentioned by three interviewees, is of particular relevance for this research because it classifies deep aquifers as mining products (PS2, PA2). Approved during Franco's dictatorship by the Real Decreto 2857/1978, it is still in force nowadays and has many tangible consequences. (a) The deep aquifers of Spain, including those in the DCFC, are not included within the water management plans (PS2), meaning that (b) the Water Framework from the EU does not come into effect at all in this case (PS2). Being regulated by the Law of Mines instead, entails that deep aquifers are treated exactly as any other type of mine; they are exploited until they dry up and they are not protected by environmental regulations (PS2). Furthermore, (c) the degree of exploitation of these aquifers cannot be tracked because their mine status spares the companies, mostly selling bottled water, from having to share their data on groundwater consumption (PS2, PA2). Therefore, this particular law results in the (d) practical privatisation of deep aquifers, a resource theoretically common, which with climate change is increasing its strategic value immensely (PA2).

Lastly, since legislation comes from the Ministry of Energy and Mines, (e) deep aquifers are not under ACA's management but are directly supervised from Madrid (PS2). This distance in decision-making and hierarchical relationship between Spanish and Catalan administrations was also considered a problem by PS1. Moreover, it was pointed out by multiple interviewees that the division of Catalonia's territory into two water administrative units, the DCFC and the CHE, makes the current water management inefficient at tackling large-scale problems, such as pollution of groundwater by pig slurry – with most pig farms being in the CHE half of Catalonia, yet DCFC's aquifers being affected too.

Socio-political resistance

Resistance from the societal and political sphere is mostly related to the *use* of aquifers. There seems to be a general reluctance to use groundwater resources, although the reasons are different for everyone.

According to PA1, for the average citizen, it is disgust that keeps them from seeing reclaimed groundwater as drinkable. PA1 considers this paradoxical, considering that rivers also carry reclaimed water. Nevertheless, a positive social reception of reclaimed groundwater is harder to achieve than that of reclaimed surface water, because most people do not see the water wastewater treatment plants upstream and therefore picture rivers as unaltered (PA1).

Still from PA1's perspective, health institutions lack trust in the potability of groundwater. Therefore, MAR projects with reclaimed water, or generally the use of groundwater to drink, are looked at with scepticism by the Catalan Health Department. Despite not intervening in the pilot testing, given its small and trial nature, they hardly greenlight larger scale projects because the invisibility of aquifers makes the Health Department feel they are uncontrollable (PA1).

At the Catalan Government level, responsible for approving the water management plans proposed by the ACA, the extensive use of groundwater is out of their comfort zone for cultural reasons explained below. On the contrary, technological approaches (e.g. dams, desalination plants, transferring between rivers) to have or "produce" more available water from

surface sources are more established. Moreover, PG3 said that the way the political system is built does not allow for changes unless those few powerful people at the very top decide to, but they are not interested in groundwater.

Cultural reasons. The reasons behind this socio-political resistance are simple but deeply ingrained in the Catalan and Spanish culture. As stated earlier, PA1 interpreted that the historical abundance of surface water in this mountainous region has resulted in a lack of need, and therefore motivation, to search for water underground. Besides, it is just invisible on an everyday basis, which makes it very hard for non-expert people to know what is underground (PG1). Additionally, PG3 underscored that, during the recent dictatorship, Franco actively drew attention to surface water and the infrastructure needed to tame it with his regular inaugurations of dams.

Altogether, this has resulted in groundwater being relegated to a second position after surface water. It is barely studied and taught about, even in the Catalan schools of engineering (PA1). Inevitably, this lack of awareness and education makes aquifers invisible and forgotten to most of the population (PA2). Even more, it influences policymaking because one only manages what one knows; as PA1 illustrates “if you have no idea of groundwater, you will never involve it in management”.

Solutions

The interviewees proposed a very wide range of approaches to tackle the barriers hindering the *use* and *restoration* of aquifers mentioned by themselves. Depending on the strategies they put forward, these approaches can be classified into five groups: technical improvements or alternatives, research and education, changes in law and regulation, restructuring of the current WMS, and degrowth.

Technical improvements or alternatives

This approach seems very comprehensive because the participants used it to address most of the technical constraints presented, certain economic limitations, and socio-political resistance. The first solution included in this group is the straightforward idea of reducing the costs of aquifer restoration technologies, both in- and ex-situ. To PG1 this is achieved by improving the efficiency of these treatments, therefore reducing their economic burden and making the restoration of aquifers a more appealing option to increase the amount of water available, also in comparison with other options.

However, some claim that this is already the reality – PA1 assured that restoring aquifers is definitely cheaper than the technological solutions that are currently being put forward (e.g. desalination plants or bringing water with ships in times of drought), and that this claim can be scientifically proven. Even more, PG2 said that these purely technological approaches require a lot of energy to work and, therefore, they do not really solve the problem of water but just transfer it to energy.

PA2 would agree with this notion that increasing the quantity or efficiency of the technologies used does not address the root of the problem, which they consider to be the current model of “infinite thirst”. They go a step further and call for more structural changes, such as degrowth, which will be further developed on its own in a later section. Others also see plenty of disadvantages when using these technologies. They complicate the WMS (PS1), they pollute as a side effect (PA2, PG3), and inevitably raise the water bill (PA1).

Across most interviews, there seemed to be a consensus that the current Catalan water management model relies too much on these technologies. PS2 summarised it by saying that “one of the biggest mistakes that the Catalan administration has been making (for many years now) is putting all the eggs in the same basket, trusting that the physicochemical technology will solve these types of problems”.

Nonetheless, the participants still see value in these technological tools and, therefore, did not advocate to stop using them altogether but suggested ways to mitigate their negative impacts as much as possible. PG3 advised using as little technology as needed and focusing all efforts on problems that only humans can cause and solve, such as removing micro-pollutants. Alternatively, PA1, PA2 and PS2 proposed changing the type of technology used, often suggesting nature-based solutions as more sustainable substitutes.

Research and education

All except one interviewee (PS1) alluded to the large potential of research to solve the problem of lacking knowledge related to aquifers. More research, monitoring, and pilot programs are key to demonstrating that groundwater is much cheaper than the massive technologies used to address the water crisis (PA1); and to test in Catalonia technologies that have been successfully implemented in other European countries (PS2, PA1, PG2).

Moreover, investigation also enables setting indicators to facilitate the quantitative and qualitative assessment of the state of groundwater bodies (PG1); being able to directly evaluate the socio-economic and environmental impacts of transferring water between regions at smaller or bigger scales (PG3); and continue convincing the Health Department of the safety of reclaimed water (PA1) therefore opening the space for an increased *restoration* and *use* of groundwater.

Subsequently, PA2 calls for “more studies, more underground mapping, more knowledge about the groundwater flows, and further formalising the relationship between what you do in the soil and what happens underneath.” A holistic approach to research is needed to reach a deeper understanding of the actual role of aquifers, as linked to the territory where they are located, to better inform their management (PG3).

Lastly, according to the interviewees, it is not only a matter of conducting research but also of communicating the results. In this regard, the CACBGI (in collaboration with Catalan, Spanish, and international research institutes) is investing in creating educational content to

spread the results of their research on water reclamation among the population to increase understanding and consequently acceptance (PG2).

In more general terms, PA1 advocates for conducting awareness-raising campaigns as an easy solution to socio-political resistance and PA2 proposes measures to increase the overall visibility of aquifers by, for example, putting up signs with their names in paths and roads as it is currently done with rivers and lakes. Furthermore, PA2 believes that “politically, aquifers can play a very large role in reconnecting people with their place, understanding the relationship between land use and water management, and empowering communities to make user associations”.

Changes in law and regulation

First and foremost, Spain should fully transpose the European Water Framework Directive of 2000 (PS2), which committed EU member states to protect and, where necessary, restore water bodies in order to reach good status (both chemical and ecological), and to prevent deterioration (*Water Framework Directive*, 2024). If the transposition into national law were done correctly, this would be incompatible with deep aquifers remaining under the regulation of the Law of Mines. Then, the deep aquifers in the DCFC would subsequently be under the control of the ACA, and their *use* and *restoration* included in the water management plans accordingly (PS2, PA2).

Within the current legislation, concrete reforms could also improve the condition of groundwater significantly. PG1 explained that changing the legal framework is essential to see changes on the ground because the administration always acts according to the norms and adapts as they change. In their view, pollution and overexploitation of aquifers would reduce as the thresholds for acceptable contamination lower and the definitions of minimum environmental flow increase.

Two main approaches were suggested by the interviewees to deal with the inefficiency of the current WMS at addressing problems across water administrative units, such as the

previously mentioned pollution of groundwater with pig slurry. For this concrete issue, PS1 exclaimed that the EU should increase the fine that the Spanish government is already paying for polluting groundwater, to force it to be more strict with pig farming. This idea comes from the fact that this ecologist organisation already brought the case to the European Parliament, which condemned the Spanish State to pay a fine periodically because it does not comply with slurry pollution policies, but the State has kept paying the fines instead of making the necessary changes (PS1). In more general terms, and from their personal opinion, PS1 believes in the urgent need to become independent from Spain as the ultimate solution to all Catalan problems, including those of the WMS.

Secondly, PG3 suggested decentralising the water management planning even more into river basin units, an idea also supported by PA2. The reasoning behind this is that at the river basin level people have a stronger connection with the territory and therefore are more concerned with its conservation when planning any interventions (PG3). This vision will be further developed below.

Restructuring of the current water management system

On how to overcome the multiple barriers identified, at some point most interviewees talked about structural changes that would bring back water management to the territory and to its people.

Many suggested decentralising and localising water management planning by giving more political weight to regional proposals. This is because the water management world is very site-specific (PG2), and therefore must incorporate local knowledge (PG3, PA2, PS2). Concretely, PSG talked about recovering the Basin Councils, participatory decision-making organisms initially planned to be an integral part of the WMS in the DCFC, legally approved but never constituted. Similarly, PG3 proposed introducing a new legal form to holistically administrate each basin's hydro-social cycle as they called it. In addition, PSG suggested

setting shorter-term goals, maybe on an annual basis, to make the water management plans more tangible to everyone.

Others talked in terms of increasing the quantity and quality of citizen participation. They asserted that having a period of public consultation every six years is not enough (PA2), nor €100,000 assigned from a budget of almost 2.5 billion euros (PSG). PA2 also indicated that improving the spaces of deliberation requires increasing the presence of science, but also of broad local knowledge. Moreover, the population from the DCFC should be encouraged to take the established legal formula of user associations and form them among aquifer users, to prevent the ACA from seeing certain aquifers as less valuable (PA2).

Another path to structural change that came up during the interviews was prioritising water conservation over other interests, and accordingly changing from a model of supply-side management towards demand-side management (PA2). According to PA2, this could be done by increasing the capacity of the ACA to influence the other departments of the Catalan Government regarding their plans and policies. Alternatively, actually creating a powerful Agency of Catalonia's Nature to achieve the integral approach to water management that is needed, another concept planned and approved by the government but not put into practice yet (PA2).

Last but not least, in line with the concepts of social and climate justice, the idea of enforcing economic reparations was also introduced by the participants. They stated that economic compensations should be paid by all industries polluting or over extracting (ground)water; in case of any type of water transfer between regions; and to account for virtual water. These are based on the assumption that putting a price on the scarce resource that (ground)water is, will mark its value and make the consumer more rational (PG3). The principle is the same in all cases, if the impacts on the territory are not assessed and taxed, consumers pay a much lower price than the problems they generate (PS1). Hence, if all the drawbacks were accounted for, well-managed groundwater would ascend in the unwritten ranking of

priorities that guides the current WMS and help reduce the use of surface water sources, which have a great impact on biodiversity (PA2).

Degrowth

The interviewees also alluded more or less directly to the concept of degrowth when suggesting solutions. PA2 declared straightforwardly that the current model of “infinite thirst”, as they labelled it, is fundamentally unsustainable. PS1 reflected on the fact that the water management plans of the past were made with water quantities that nowadays do not exist anymore. Also PSG referred to the same issue with the comparison “just like with banks, if we were all to withdraw the water permits we have, there would be a lack of water”. PA2 clarified that the data on the current water consumption of Catalonia supports these statements, which implies the necessity to change.

Based on PS1’s observation that problems are socialised whereas benefits are privatised, degrowth was perceived as an overarching solution to the capitalistic model that is leading to the pollution and overexploitation of resources, including water and groundwater, for the economic benefits of a few. This is the reason why PA2 urged to never decouple any solutions from the need to reduce water demand.

However, degrowth can take many concrete forms, and education was the one predominantly mentioned because as PSG put it, as a society we do not seem to have a real awareness of what the limits of water consumption are. Agreeing, PA2 requested a pedagogy of climate change and its effects on water, a pedagogy of limits, of interrelation between economic activity and territory.

Table 2

Visual summary of main findings from interviews

Solutions	Barriers			
	Economic limitations	Technical constraints	Legal conditions	Socio-political resistance
Technical improvements or alternatives	X	X		X
Research and education	X	X		X
Changes in law and regulations		X	X	
Restructuring the current WMS			X	X
Degrowth	X			X

Note. Own work. Barriers to using and restoring aquifers explicitly mentioned by the interviewees and the solutions they also proposed to overcome them.

Discussion

This section analyses the results gathered from the interviews just presented. Firstly, the Three-Layer Model of Water Governance of Havekes et al. (2016) is used to evaluate the current state (ground)water governance in the DCFC. Secondly, the research question *how to improve groundwater governance in the Catalan River Basin District to increase drought resilience* is answered with concrete recommendations. Lasty, the limitations of this study are addressed and further research is suggested.

(Ground)water governance in Catalonia

The theoretical framework of Havekes et al. (2016) dissects water governance systems according to three layers of analysis, namely the Content layer, Institutional layer, and Relational layer. Each one of these layers contains three elements to be examined – (a) Content layer: (i)

Clear policy, (ii) Knowledge and skills, and (iii) Information; (b) Institutional layer: (i) Organisation, (ii) Legislation, and (iii) Financing; (c) Relational layer: (i) Culture and ethics, (ii) Communication and cooperation, and (iii) Participation (refer to Figure 2 for a reminder).

As previously mentioned, this research approached every single one of these total nine elements with the questions *what do we have that works, what is missing,* and *how can water governance be improved* (see Appendix C for a visual summary of this process) and extracted the conclusions displayed below.

Content layer

Clear policy. In terms of clear policy, the existence of the sexennial water management plans is an essential first step. Further, the one plan currently in place is detailed and comprehensive. However, the mention of aquifers and groundwater overall is deemed insufficient, in relation to the untapped potential that they have or in comparison with the amount of times that certain technologies are discussed.

Therefore, giving more weight to aquifers' interventions would directly improve groundwater governance. Additionally, these management plans and policies should also include shorter-term goals, such as annual targets, to make (ground)water governance more efficient in promoting action and evaluating progress.

Knowledge and skills. The professionals working at the ACA, especially the hydrologists, were described as very knowledgeable and skilled in all the interviews. Moreover, the current system already has many established techniques for the quantitative and qualitative restoration of aquifers. Notwithstanding, there still exists a big lack of understanding of aquifers, which affects everyone ranging from experts to civilians.

In this regard, groundwater governance can be improved by conducting more research (e.g. on aquifers' ecosystem services). The academics interviewed opine that it is crucial to at least understand the key features of the aquifers in the DCFC (e.g. recharging rate, recharging point, approximate capacity) in order to manage them well.

Information. Nowadays, information availability in the Catalan WMS is excellent. Accurate data on the state of surface water and superficial aquifers is public and updated live (PG2). The only very relevant information that is missing is on deep aquifers that are being used for industrial purposes. In consequence, the sensible way to tackle this problem, and improve groundwater management as a result, seems to be to force private companies to be transparent about the state of the deep aquifers they exploit.

Institutional layer

Organisation. The roles and responsibilities are clear in the water framework of the DCFC. There is one main water policy making organisation, i.e. the ACA, which oversees all (ground)water governance in the region. Moreover, the administrative units at the regional and local level are clearly defined and effectively running.

However, a problem in the current organisational structure is the absence of power from the water department to influence other government departments' plans that also require water consumption. Increasing the power of the ACA would root water management back to the reality of water scarcity and ultimately improve water governance.

Besides this, the ACA would benefit from decentralising its planning process to a more local scale, since the DCFC is a very diverse territory and there is a lot of local knowledge. The Basin Councils mentioned in the following next section could be a way to make the geographical spread of this organisation more tangible.

Legislation. For the most part, the water legislation in place is on a good track in theory, but not that much in practice. The transposition of the European Water Framework Directive into Spanish law provides a robust basis for water governance. In Catalonia, this entailed the constitution of the celebrated ACA. Moreover, the Catalan Parliament has passed a series of water-related laws with a lot of potential. Namely, the Decret 86/2009, which approved the territorial deployment of the ACA, including the creation of the Basin Councils, local organisms of participatory decision-making; and the Llei 7/2020, to found an Agency of Catalonia's Nature

to bring together the protection, planning, management, restoration, improvement and study of the natural environment of Catalonia (*Agència de la Natura de Catalunya*, 2023).

Unfortunately, the content of these two promising Catalan laws has not yet been constituted. In the first case, on the basis of lacking money (Fusté, 2017), and in the second, because it is not a political priority (PA2). In addition, as previously mentioned, deep aquifers are still regulated under the Spanish Law of Mines, which is in direct conflict with the European Water Framework. Therefore, to improve groundwater governance in the studied region is fundamental to take the step of putting these regulations in (full) practice.

A more concrete aspect of the legal framework of great importance is the issue of accountability mechanisms for those who polluted (ground)water. As explained by the participant from the ACA, multiple mechanisms exist but sometimes they are unusable for many reasons (e.g. the polluter is unknown, gone, or cannot afford the costs). The present stronger regulations promoting prevention are helping reduce these scenarios of powerlessness. In the future, coinciding with Ostrom's (1990) faith in the commons, the rare political condition of aquifers should be leveraged to raise awareness among individuals to stop polluting the water body that they share with their neighbours. For the industries, economic incentives and sanctions appear to be the only option, since most are driven by money.

Financing. The financing system of the water management plans and the ACA is transparent and detailed. Even more, the budget for these plans already sets aside money for groundwater management. The current water management plan (2022-2027) assigns €4,730,000 to the "protection of aquifers" and 2,295,676 € to the "reduction of the point source industrial pollutants and decontamination of aquifers" (ACA, 2022c).

Despite these efforts, it seems like groundwater is still not perceived as a solid alternative to surface water. This may be because the former is oftentimes deemed more expensive than the latter. Although this comparison might be true in most cases, what is unreasonable is that desalination and other technological approaches, which are substantially

more expensive than groundwater, are being prioritised as alternatives. Therefore, more research is also needed to prove that groundwater is already cheaper than technological approaches, and this knowledge should be widespread to better inform water governance.

Relational layer

Culture and ethics. The geographical context shapes the culture and ethics around water management. This has led Catalonia, a coastal and mountainous land of rivers, to conceptualise surface water as the main and almost only source of water. However, some municipalities have historically supplied themselves with wells and groundwater, a valuable experience that becomes helpful in the present times.

Nonetheless, there is insufficient awareness of aquifers and, by extension, groundwater. This is particularly problematic because it frustrates a positive social reception of aquifers as powerful tools and hinders political willingness, or even interest, in the use of groundwater. Hence, campaigns to increase aquifers' visibility and more science divulgation are urgently needed.

Communication and cooperation. As previously mentioned, the public availability and transparency of water-related data are strengths of the current water governance system. Yet, communication among all the stakeholders involved in (ground)water management is missing to a greater or lesser degree. Inevitably, going beyond communication to achieve cooperation does not occur. Each of the departments of the Catalan Government draws up its plans of action separately and competes for the same limited water instead of discussing and reaching compromises.

Similar dynamics rule the next level, the regional governance. The DCFC and the CHE, the two administrative units in which Catalonia is divided for water management, also do not align their approaches as much as they should, for example to tackle the issue of pig slurry pollution (which is mainly rooted in the CHE region but affects DCFC aquifers too).

This modus operandi is inefficient and has to evolve. Water is needed everywhere, and for all types of activities (e.g. agriculture, tourism, industry, land planning), and in the current context of climate change, such a scarce natural resource is gaining value. Therefore, its allocation must be increasingly thoughtful. Inter-departmental and inter-administrative relationships should be based on coordination and cooperation for sustainable (ground)water governance.

Participation. Last but not least, participation in decision-making is key to acceptance of any type of policy. The water management plans of the DCFC have a period of public consultation, before they are definitely approved, in which anyone can make suggestions that will then be considered and may be implemented in the updated version of the plans (ACA, 2022d). However, this has not been considered enough, more frequent checks with the population are needed. Additionally, the critical voices from civil society should be more involved in the process.

In the last water management plan, only €100,000 of the total budget was earmarked to improve public participatory processes, which is too little for them to be influential. For this reason, increasing the budget allocated would improve the quality of stakeholders' participation and future water governance.

Recommendations

Water governance continues to be a major challenge in the Mediterranean region (Global Water Partnership Mediterranean, 2023) but this multi-layer analysis of the results sheds light on how it could be upgraded in Catalonia. Three lines of action should be simultaneously tackled in order *to improve groundwater governance in the Catalan River Basin District.*

First and foremost, the necessary legal amendments need to be made for deep aquifers to be regulated under the European Water Framework. Only then will we be able to talk about

actual integral (ground)water governance in the context of the DCFC. In line with the literature, recovering all these resources for public use would contribute to a perceptive change of groundwater as a more desirable and cheap nature-based alternative to the technological approaches mainstreamed these days (Bernello et al., 2022).

Secondly, the study of aquifers should continue and be shared. An accurate understanding of aquifers' flows can better inform policy-making and future adaptation plans. Besides, a knowledgeable and groundwater-aware population can keep all stakeholders in check (Botero et al., 2013). For this to be effective though, participatory mechanisms should receive more funds.

Thirdly, some structural changes are required to make the current system of water management, and groundwater, more sustainable. Either the projected Agency of Catalonia's Nature is finally put in place to supervise the protection of the natural resources in the territory, or the ACA should be attributed more power to influence the plans of other departments that are inherently consumers of (ground)water and often also polluters of it (e.g., agriculture, tourism, energy) (Smajgl et al., 2016). In any case, interdisciplinary and interdepartmental cooperation, as well as striving to consume within the real water availability, are vital elements for the future of (ground)water governance.

If implemented, these reforms would enhance the use and restoration of aquifers, thereafter increasing the water storage capacity of the DCFC. Given that Catalonia has seen an increase in precipitation variability, leveraging the storage capacity would help mitigate this effect of climate change and ultimately translate into *increased drought resilience* for the region.

Limitations and further research

Three main limitations were identified in the course of this research. First, despite data saturation was reached in the fact that no new barriers and/or solutions were mentioned in the last couple of interviews, great differences were identified between the interviewees' answers

depending on their background (i.e. governance, academic, civil society sphere). While this may only be a coincidence found among the selected participants, future research should test these possible correlations and look into how to best inform policymakers about all the existing and divergent opinions.

Another point of consideration is the unexpected finding that what happens in the territory of the water administration unit of the Hydrographic Confederation of the Ebro River has quite some influence on the state of groundwater bodies in the area of the DCFC, to which the study was limited. Therefore, further research could expand on the present study by enlarging the scope to include water governance in the CHE.

Lastly, the participants were not directly asked about aspects that work in the current WMS, which restricted the amount of information available for the researcher to answer the first question of the Three-Layer Model. However, the interviewees themselves mentioned enough positive aspects to keep that section in the discussion of results.

Conclusion

In the context of historical drought in Catalonia, this study reviewed the WMS in place and identified an untapped potential of aquifers as tools for climate change adaptation. Subsequently, this thesis set out to answer the research question *How to improve groundwater governance in the Catalan River Basin District to increase drought resilience?*

For this purpose, semi-structured interviews were conducted with key stakeholders involved in the water governance of the DCFC. The participants provided significant insights into the reasons why aquifers are not being restored and used to their full potential, and ways to overcome the existing barriers. Inductive coding revealed barriers of (a) Economic, (b) Technical, (c) Legal, and (d) Socio-political nature; as well as solutions requiring (a) Technical improvements or alternatives, (b) Research and education, (c) Changes in law and regulation, (d) Restructuring the current WMS, and (e) Degrowth.

To our knowledge, this is the first time that these barriers are uncovered systematically and explicit solutions researched for this niche issue. Therefore, reaching data saturation with such a diverse sample of participants provides robustness to the information gathered. Nonetheless, further research should be conducted with a larger number of participants and considering the inter-territorial relationships between the DCFC and the CHE.

The discussion of results using the Three-Layer Model of Water Governance has many implications for the future of groundwater governance in the studied region. Despite the current WMS has a lot of valuable assets, there is room for improvement, especially regarding the role of aquifers. It is imperative to make the necessary legal amendments to include deep aquifers under the national and regional water regulations so that they are managed by the Catalan Water Agency. Moreover, the research and education of these mysterious bodies of water must continue to make politicians and the population more aware of their existence, value and potential. Finally, the findings suggest that there is a need for water governance to be embedded in the policies and plans of other governmental departments, because it is a scarce resource which management should involve coordination rather than competition.

Following these recommendations will leverage the use and restoration of aquifers in the Catalan River Basin District, adding more storage capacity to the system. This will improve its groundwater governance by addressing the issue of increased variability in precipitation, therefore making this region more resilient to drought. Furthermore, these findings will hopefully pave the way for other world regions suffering from droughts to rethink the potential of their aquifers and groundwater resources.

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Appendix A. Interview Guide

The following questions were translated to English from the original in Catalan.

Fixed questions

Opening questions

- Could you elaborate on your positionality in relation to the water management sector in Catalonia?
- What are your thoughts about the latest Water Management Plan for the Catalan River Basin District (for the period 2022-2027)?

Core questions

- What do you know about the current role of aquifers in the context of water management in Catalonia?
- Do you believe that (the restoration of) aquifers have potential for climate change adaptation in Catalonia?
    - Do you think they have untapped potential, especially in terms of drought management?
- Which do you consider the main challenges in the restoration/use of aquifers?
    - From your expertise, can you identify any further specific challenges?
- Can you come up with ways in which these challenges could be overcome?

Closing questions

- Would you like to add anything else?

Examples of interviewee-specific questions

- If I am not mistaken, you defend holistic and intersectoral water management. How do you see aquifers located within this tangled mess of options and coordinated policies to face drought?
- Why do we barely use groundwater in Catalonia? In the interview for the ___ podcast you pointed at cultural reasons, which ones were you referring to?
- Could you please elaborate on the part of the ___ manifesto that talks about groundwater and aquifers?

Appendix B. Informed Consent Form

The following form was translated to English from the original in Catalan.

Informed Consent Form

Increase Catalonia's resilience to drought: The role of aquifers

Dear,

We appreciate your interest in participating in this research project.

This document explains what this implies and how the research will be carried out, so that you have all the information before agreeing to participate. Please read it carefully. If you have any questions, do not hesitate to contact us through the email addresses that you will find at the end of these pages.

What is the research about?

It is a Bachelor's thesis project from the University of Groningen. It aims to propose measures that improve the future water management plans of the Catalan River Basin District in relation to droughts. This work is based on the assumption that in order to increase the resilience of the territory against drought, it is necessary to adapt to the increasing variability in precipitation. Specifically, this study focuses on the role that aquifers could have in case of being restored.

In order to identify the main obstacles of this restoration, and how to overcome them, qualitative research methods will be used. The intention is to interview various professional profiles involved in water management in Catalonia in a more or less direct way – from administrative bodies, or research, to NGOs – in order to represent the existing diversity of points of view. It is for this reason that you have been invited to participate.

What does it entail to participate?

1. Arrange a day to do the interview.
2. Respond mainly to 6 questions related to the research topic. We expect the interview to last between 20 and 40 minutes.

Do you have to participate?

Your participation in this study is entirely voluntary.

If you wish to withdraw your consent of participation or prefer not to answer any of the questions in the interview, you can do so without any consequences and no explanations will be asked.

Are there risks in participating?

Their participation in this study should not pose any physical, mental or work risk.

Are benefits derived from participation?

You will obtain no direct benefits from your participation in this study. However, this research can contribute to expanding knowledge in relation to how to increase Catalonia's resilience to drought.

Data processing

- Your interview will be recorded in audio, except if you indicate otherwise at the end of this document.
- Only the researcher and supervisor of this research project will have access to the original recordings and complete transcripts of the interviews. These files will be stored following the general data protection guidelines (GDPR) of the University of Groningen, on the Y-Drive platform provided by the same institution.
- In order to guarantee the confidentiality of the participants, the transcripts of the interviews will be anonymised before being cited or shared with someone external to the researcher and project supervisor.
- In the event that you withdraw your participation consent, your data will be deleted within a maximum period of one week.
- All data collected during the research will be stored until the end of October 2024, after which they will be irreversibly deleted.

Results of study

Theoretically, this final degree project will not be published. In the event that this changes, you will be informed of the new situation and you will have the possibility to decide whether you want to continue participating in the research or you want to withdraw your consent without obligation. The main results of this study will be presented during the oral defense of the thesis, which can be attended by all the professors and students of the Campus Fryslân faculty of the University of Groningen. Once the research is completed, the results can be shared with you if you indicate it likewise at the end of this document.

Ethical approval

This research project has obtained ethical approval from the Ethics Committee of the Fryslân Campus, of the University of Groningen. Everyone involved in the research respects the indicated ethical standards.

Informed consent

Please sign below if you give your informed consent to participate in this research as an interviewee.

Remember that you can withdraw your consent at any time without consequences.

Interviewee	*Researcher*
Name: Signature: Date:	Name: Paula Perea Garcia Signature: Date:

Cross the desired options:

☐ I prefer my interview not to be recorded in audio.

☐ I want to receive the results of the research once it is finished.

Contact details

Researcher - Paula Perea Garcia: p.perea.garcia@student.rug.nl

Supervisor - Raúl Cordero Carrasco: r.r.cordero.carrasco@rug.nl

Appendix C. Visual Summary of Discussion

Table 3

Application of the Three-Layer Model of Water Governance with the results of the present research on groundwater in the context of the DCFC

		What do we have that works?	What is missing?	How can (ground) water governance be improved?
Content layer	Clear policy	- Water management plans every 6 years.	- More mention of groundwater. - Shorter-term goals.	- More mention of groundwater. - Yearly goals.
	Knowledge and skills	- Professionals (hydrogeologists) working at ACA. - Established techniques to restore aquifers quantitatively and qualitatively.	- More understanding of aquifers by experts and society.	- More research to at least understand the key features of aquifers in the DCFC (recharging rate, recharging point, approximate capacity).
	Information	- Live and public updates on the state of surface water and surface aquifers.	- Access to information on deep aquifers (for industrial uses).	- Mandatory transparency in state of deep aquifers used for industrial purposes.
Institutional layer	Organisation	- One clear water policy maker: ACA, which is responsible for (ground)water governance. - Clear water administrative units at the regional and local level.	- Inter-departmental influence.	- ACA has more influence in other government departments plans. - Decentralisation.
	Legislation	- European water framework. → Spanish transposition into Water Law. - Catalan Laws with a lot of potential approving (consells de conca, agència de la natura de	- Putting in practice already approved legislation). - Deep aquifers included under the water laws. - Sometimes it is impossible to enforce accountability (e.g.	- Make the step to put all these regulations in practice or make them work totally.

		Catalunya). - Accountability mechanisms for those who polluted aquifers.	collective, unknown, dead).	
	Financing	- Detailed budget to execute water management plans. - Budget planned for aquifer restoration projects.	- Groundwater being “as cheap as” surface water (at least enough to be a reasonable alternative).	- Research to show that groundwater is already cheaper than technological approaches.
Relational layer	Culture and ethics	- In some municipalities a history of groundwater use (PS1)	- Awareness of aquifers and groundwater overall. - Good social reception of groundwater. - Political willingness to use groundwater.	- Campaigns to increase visibility. - More science divulgation.
	Communication and cooperation	- Transparent and public data.	- Power of ACA to influence other policies (not only directly water related).	- Inter-departmental coordination (e.g. water informing agriculture, tourism, urban planning). - Effective cooperation between CHE and ACA to address cross-administrative issues (e.g. as aquifers pollution with pig slurry).
	Participation	- Water management plans’ period of public review.	- More frequent check ups with population. - Integration of the critical voices from civil society organisations.	- Increase budget allocated.

Note. Own work based on the framework of Havekes et al. (2016).