Controlling water infrastructure, codifying water knowledge. Institutional responses to severe drought in Barcelona (1620-1650)

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ABSTRACT: Combining historical climatology and environmental history, this article examines the diverse range of strategies deployed by the city government of Barcelona (Catalonia, NE Spain) to confront the recurrent drought episodes experienced between 1626 and 1650. Our reconstruction of drought in Barcelona for the period 1525-1821, based on *pro pluvia* rogations as documentary proxy data, identifies the years 1626-1635 and 1640s as the most significant drought events of the series (highest drought frequency weighted index and drought duration index). We then focus on the period 1601-1650, providing a timeline that visualises rain rogation levels in Barcelona at a monthly resolution. Against this backdrop, we examine institutional responses to drought and discuss how water scarcity was perceived and confronted by Barcelona city authorities. Among the several measures implemented, we present the ambitious water supply projects launched by the city government, together with the construction of windmills as an alternative to watermills, as a diversification strategy aimed at coping better with diminishing water flows. We pay special attention to the institutional efforts to codify the knowledge about Barcelona's water supply, which in 1650 materialised in the Book of Fountains of the City of Barcelona (*Llibre de les Fonts de la Ciutat de Barcelona*). This manual of urban water supply, written by the water city officer after three decades of experience in his post, constitutes a rare and valuable source to study water management history but also includes significant information to interpret historical climate. We analyse the production of this manual in the context of three decades marked by recurrent episodes of severe drought. We interpret the city government aspiration to codify knowledge about urban water supply as an attempt to systematise and store historical information on infrastructure to improve institutional capacities to cope with future water scarcities.

1. Introduction

Around July 1650, during an intense episode of drought in Barcelona, the city water officer ("mestre de les fonts") Francesc Socies started writing a book that described in great detail the water supply and distribution system of the city. At the time, Socies had been in his post for over thirty years, overseeing the city's fountains and water supply, and was approaching retirement. After decades of coping with drought frequently, and well-aware of the precious experience gathered by Francesc Socies, the city government had asked him to compile his knowledge about Barcelona's water supply system. The resulting book should perpetually be kept in the city archives to shed light on the work of future water city officers and improve urban water management. In November 1650, Socies delivered what became known as the *Llibre de les Fonts de la Ciutat de Barcelona* ("Book of Fountains of the City of Barcelona") (Archival source AS1).

This article focuses on the three decades (1620-1650) leading to the codification of knowledge about Barcelona's water supply into the Book of Fountains and examines them from the perspective of historical climatology and environmental history. Our analysis reconstructs the severe droughts experienced in the city during this period and examines the strategies followed by the city government to cope with them, contributing to the growing scholarship on societal adaptation to past climate changes (Degroot, 2018). First, drawing on *pro pluvia* rogations (rain rogations) as proxy data, we identify the years 1626-1635 and 1640s as the most significant drought events that occurred in Barcelona during the period 1521-1825 (highest drought frequency weighted index and drought duration index of the series). This previously unpublished drought reconstruction is the first contribution of our work, which confirms previous research on historical climatology that had pointed to the years 1625-1635 as severely dry (Díaz, 1984; Martín-Vide and Barriendos, 1995; Rodrigo and Barriendos, 2008). These results are coherent with a systematic analysis of 165 tree-ring series in the Mediterranean for the last 500 years, which points to an acute period of drought between 1620 and 1640, an episode that affected the whole Western Mediterranean (Nicault *et al.*, 2008).

Second, following scholarship on the social response to past climate variability (Pfister, Brázdil and Glaser, 1999), we examine the diverse range of strategies deployed by the Barcelona city government to confront the recurrent drought episodes experienced during the years 1626-1650. In contrast to the development of historical climatology in Catalonia, research on the human response to past climate variability is still scarce (Martí Escayol, 2019). The work of Antoni Simon i Tarrés, who highlighted the importance of drought among the complex interaction of factors that triggered social unrest in Catalonia during the late 1620s and 1630s stands out among the few existing publications on the topic (Simon i Tarrés, 1981, 1992). Others have underlined that climate conditions in the 17th century accentuated the agricultural, social and political crisis (Serra i Puig and Ardit, 2008). The impact of climate variability in the Iberian peninsula during the 17th century has also been stressed by Geoffrey Parker, who pointed out that Spain "suffered extreme weather without parallel in other periods, particularly in 1630–2 and 1640–3" (Parker 2013:289). Parker examined the Catalan revolt against the Spanish King Philip IV (1640-1652) emphasizing the key impact of extreme weather events in Catalan society (Parker, 2013).

However, none of these authors examined in detail human response to climatic variability in Catalonia during these years. More recently, by focusing on the case of the town of Terrassa (Barcelona region), Mar Grau-Satorras has analysed how local communities combined different strategies to cope with drought during the 17th century,

including infrastructural, institutional and symbolic responses, which changed throughout time (Grau-Satorras *et al.*, 2016, 2021; Grau-Satorras, 2017). Along these lines, our research focuses on the case of Barcelona as an example of Western Mediterranean urban agglomeration (40,000 citizens) under severe environmental stress. Among other institutional strategies in response to drought and diminishing water flows, we discuss the production of the Book of Fountains, underlining the relevance and novelty of the attempt of Barcelona city government to codify water knowledge in the form of a book for future urban city officers.

In line with research in the historical climatology re-assessing traditional documentary sources or presenting innovative ones (Adamson, 2015; Veale *et al.*, 2017), our research draws attention to the potential of urban water supply manuals as a rare but significant source to be considered to critically interpret institutional responses to droughts. While the Book of Fountains is known in Catalan historiography (Voltes Bou, 1967; Perelló Ferrer, 1996; Cubeles, 2011), it remains unpublished and has not been studied in depth. After carrying out the first complete transcription and analysis of the text, this is the first article that contextualises the writing of the Book of Fountains within the severe droughts experienced in Barcelona during the 17th century. Manuals of urban water supply constitute rare documentary sources, and we have only identified one similar book: *Le Livre des Fontaines de Rouen*, written by Jacques Le Lieur between 1524 and 1525 in the city of Rouen, France (Sowina, 2016).

The article proceeds as follows. In the next section, we provide an overview of the methods and sources used to reconstruct droughts during our period of study, as well as to review the institutional responses to it. In the "Results" section we present three previously unpublished figures that show the drought frequency weighted index and drought duration index for the period 1521-1825, together with a timeline that presents rain rogation levels in Barcelona between 1601 and 1650 at a monthly resolution. The results about institutional responses are presented in the form of two diagrams showing the main strategies followed by the city government and the specific years they were implemented. Next, the discussion section is subdivided in three parts. First, we examine how institutional responses to drought intertwined with urban and political conflicts. Second, we discuss the Book of Fountains as a strategy for codifying knowledge transmission and improving urban water management. Third, we analyse the Book of Fountains as a tool to enhance water infrastructure control. In the conclusions, we summarise the relevance of our local case study and point out the potential of urban water supply manuals as historical sources for both climate reconstruction and past climate adaptation.

2. Methodology and Sources

2.1 Drought reconstruction

The climatic conditions during the 17th century can be considered as part of the climatic episode known as the Little Ice Age (LIA). Research on historical climatology has pointed to a higher frequency and severity of cold spells during this episode (Pfister, Schwarz-Zanetti and Wegmann, 1996; Pfister *et al.*, 1998; Ogilvie and Jónsson, 2001; White, 2014). More recently it has also identified and analysed a general increase in the irregularity of rainfall patterns, manifested in the emergence of hydrometeorological extreme episodes with great social and environmental impact. At the climatic scale, in the Spanish Mediterranean this increase in the frequency and severity of extreme hydrometeorological events manifests in periods of around 40 years for the case of extraordinary rainfalls leading to floods (Barriendos and Martin-Vide, 1998; Llasat *et al.*, 2005; Barriendos *et al.*, 2019).

Rain rogations have been successfully used as a proxy for the reconstruction of rainfall variability (Martín-Vide & Barriendos, 1995; Barriendos, 1996; Barriendos, 1997). Rogations were a mechanism to respond to environmental stress, in this case drought. The institutions involved (agricultural guilds, city councils, cathedral chapters) have left reliable and detailed records, with data at a daily resolution. In Catalonia, rain rogations are classified in five levels, according to their severity. These categories can be identified by the typology of religious liturgies, from simple rogations inside the church (low, level 1) to pilgrimages to sanctuaries (critical, level 5). An integrated index is obtained by weighting data according to the severity of each level of rogation. This index is standardised so that it can be compared with other populations and regions (Martín-Vide and Barriendos, 1995).

Drawing on previous research based on this method and sources, Figure 1 provides a general view of the frequency of extreme droughts for the period 1501-1861 with data from four Catalan cities near the Mediterranean coast at a yearly resolution (Barcelona, Girona, Tarragona and Tortosa) (data adapted from Oliva *et al.*, 2018). This general view allows to identify many recurring events of medium intensity and some of very high intensity for the Catalan coast. The relevant drought events identified are the following: 1520s, 1540s, 1560s, 1620s (c. 1625-1635), 1750s, 1812-1824.

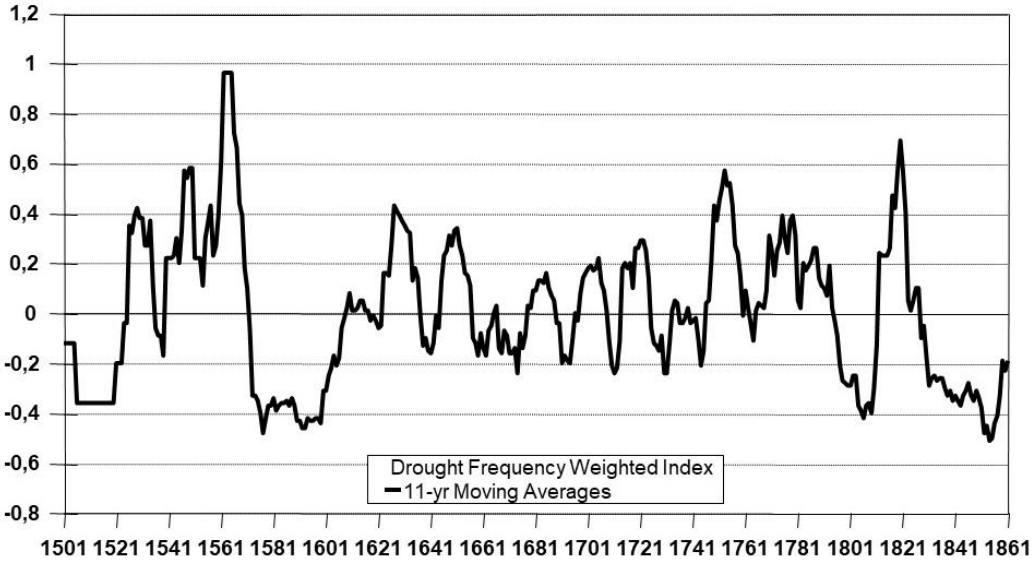


Figure 1. Drought Frequency Weighted Index (1501-1861). Standardised values. 11 years moving averages from four cities: Girona, Barcelona, Tarragona and Tortosa. Data adapted from Oliva *et al.*, 2018.

In relation to 17th century Catalonia, Figure 1 shows two pulses of drought during our period of study (1620-1650): a higher one approximately between 1625-1635 and a lower one immediately after. This assessment is coherent with the systematic analysis of 165 tree-ring series in the Mediterranean for the last 500 years, which point to an acute period of drought between 1620 and 1640, an episode that affected the whole Western Mediterranean (Nicault *et al.*, 2008).

In order to document the impact of drought in Barcelona and the institutional measures to adapt to it, our research delves in the Catalan capital leaving aside the other three cities included in Figure 1. In first place, we apply the drought frequency weighted index displayed in Figure 1 to the local data of Barcelona (see Figure 4 in the section "Results", previously unpublished). Second, we take advantage of a variable that provides useful information to assess the length of drought episodes. In the case of Barcelona, the level 2 of *pro pluvia* rogations involved the public exhibition of a specific relic: the remains of Santa Madrona (Martín-Vide & Barriendos, 1995). The public exhibition of this relic in the high altar of the Cathedral lasted until the authorities established that the drought was over. In that moment, the urn containing the Saint's remains was taken back to the Chapel of Santa Madrona in the near mountain of Montjuïc. This liturgical pattern introduces the possibility of analysing the duration of drought episodes as perceived by local authorities, something that has not been studied in this geographical context. By accounting for the amount of days per year that the level 2 of drought was active in Barcelona and standardising the result to make it comparable with other cities, we obtain an annual index of drought duration for the period 1521-1825 (see Figure 5 in the section "Results", previously unpublished). Finally, since the data allows for an analysis at a monthly resolution, we aim at producing a timeline to describe the behaviour of drought and the different rogation levels focused on the study period 1600-1650. This timeline (see Figure 6 in the section "Results", previously unpublished) allows to distinguish if the dry months were sporadic and irregular or appeared as a persistent anomaly for long periods.

2.2 Institutional response

Our analysis of the institutional response to drought focuses on the period 1620-1650. We provide a qualitative analysis of the records produced by the Consell de Cent (city government) in relation to water management during these years. Most of all, we interpret the creation of the *Llibre de les Fonts* in the context of the frequent drought of our period of study. This rare source, kept at the city archives, was written by the water city officer Francesc Socies during the summer of 1650, at the request of the city government (AS1, Figure 2; AS2). The Book of Fountains is a manual about urban water supply, a text where Socies provides instructions that codify both the knowledge of his profession and the experience from his job position, where he was posted between 1620 and 1650. The manual aimed at guiding future interventions in the supply system and communicating what future water city officers should know.

Figure 2. First page of the *Llibre de les Fonts*, Manuscrits, L-15, Arxiu Històric de la Ciutat de Barcelona (AHCB).

The structure of the book follows the water distribution system and describes it as an interconnected network, from the drainage underground canals in the hills of Barcelona known as "water mines" (*qanats*) to the city fountains. The author indicates with high precision where each element is located, both for those visible and those hidden from view, underground or behind walls (water taps, pipes, water tanks or wells). In addition, throughout the book, the author provides a calendar for the system's maintenance within a particular urban space and time. Socies specifies where to intervene and how often, for instance in relation to the cleaning of pipes and curtailing the growth of trees' roots that can disrupt sections of the system (e.g. every two, four of five years). Nevertheless, Socies' temporal specifications do not only apply to maintenance, but also to key historical information about water property rights. Finally, Socies refers several times to droughts and the lack of water supply experienced in the city during the study period.

In addition to our analysis of the Book of Fountains, a review of the secondary literature on urban history helped to identify valuable works that refer to measures approved by the city government during the 17th century to cope with drought and diminishing water flows (Voltes Bou, 1967; Perelló Ferrer, 1996). We have also reviewed the leaflets published by the city government during our period of study and found several connected to water management. In the first place, we located a pamphlet in defence of a project to build an irrigation canal to bring waters from the Llobregat River to Barcelona (AS3, published in 1627). Though this project was not carried out, we have traced several references to it in city chronicles and meeting records during the following years (AS4 and AS5). Our review has also identified four leaflets connected to a legal conflict concerning water rights, which in 1634 brought face to face the Barcelona city government and the water officer Francesc Socies with the Cathedral's Chapter (AS6, AS7, AS8, see Figure 3, and AS9).


POR
LA CIVDAD DE
BARCELONA, Y
FRANCISCO SOSSIES
MAESTRO DE LAS
FVENTES,
CON
EL CABILDO DE LA IGLESIA MAIOR
acerca de las cenſuras declaradas contra
el dicho SOSSIES.
BARCELONA
En caſa de Sebaſtian y Iayme Matevad Impreſſor de la Ciudad, y de ſu
Vniuerſidad. Año 1634.

Figure 3. First page of leaflet "Por la civdad de Barcelona y Francisco Sossies, maestro de las fventes, con el Cabildo de la Iglesia Maior acerca de las censuras declaradas contra el dicho Sossies", 1634 (AS8). Source: F.Bon. 10964, Biblioteca de Catalunya.

3. Results

3.1 Drought reconstruction

Drawing on *pro pluvia* rogations, Figure 4 shows a distribution of drought frequency in Barcelona between 1521 and 1825 with different degrees of intensity. By using yearly weighted indexes, we identify the decades of 1560s and 1625-1635 as the two most significant drought events of these three centuries in the city. The latter, however, stands out for its extreme severity. Moreover, there was no similar experience with drought in the previous 50 years (approximately 1570-1620).

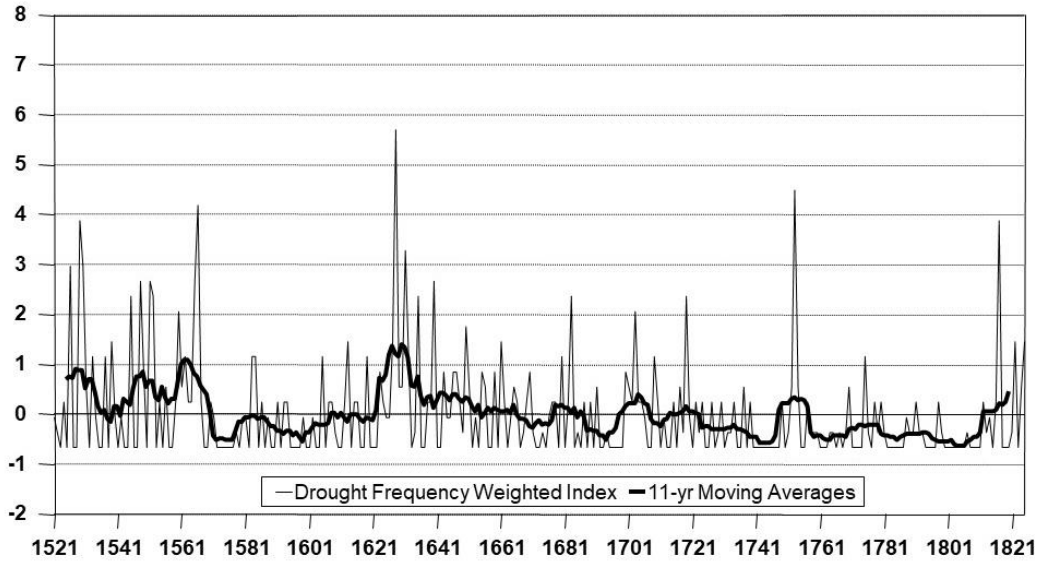


Figure 4. Drought Frequency Weighted Index. Standardised values. City of Barcelona (1521-1825). Data improved from Martín-Vide and Barriendos, 1995.

Through the development of an index of drought duration based on the records about the public exhibition of Santa Madrona relic, Figure 5 shows that the drought experienced in Barcelona during the late 1620s was perceived as longer than any other registered until that time. While it is difficult to extract more details with these historical records, it is evident that the drought registered had an extraordinary magnitude. However, the long duration of the rain rogations may also be related to the perception of an extreme anomaly by the city authorities, since almost no drought conditions had been experienced in the previous 50 years.

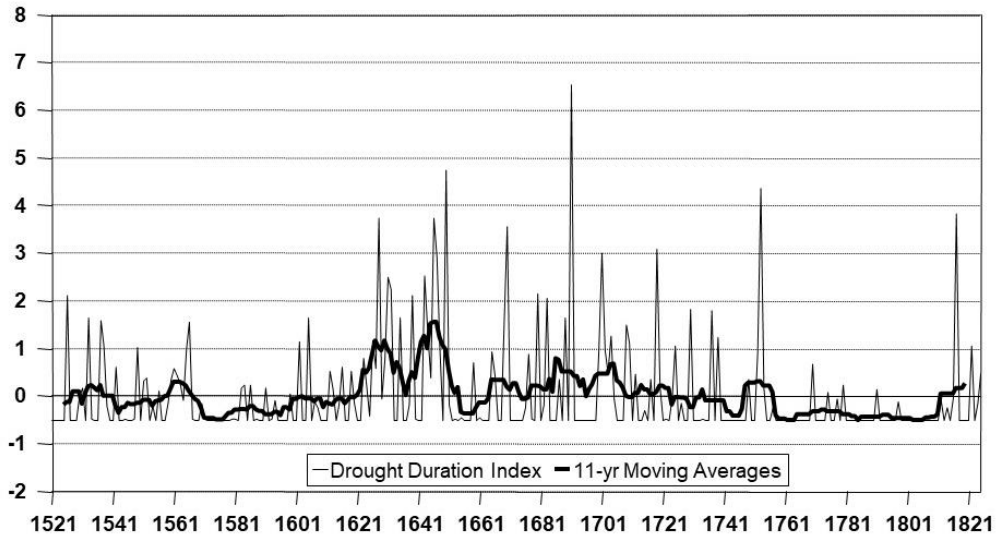


Figure 5. Drought Duration Index. Standardised values. City of Barcelona (1521-1825).

The analysis of drought duration presented in Figure 5 reveals another significant issue. After the severe 1620s drought, which extends into the first part of the 1630s, there was a less intense episode, very close in time, around the 1640s. On this occasion the duration of rain rogations of level 2 –involving the exhibition of Santa Madrona– was even longer than in the previous episode (Figure 5). These results do not allow to analyse in detail the development of the drought episode but provide an entry point to the human response to an extraordinary climate event. The first drought period of the study (1620s to the first half of 1630s) had such a social impact that the almost consecutive episode of the 1640s generated a proportional response. In view of the impact of drought on water resources and with limited references available after two generations without similar events, the duration of the rain rogations may have been extended as a response against a challenging situation for local authorities.

Finally, Figure 6 delves into the first half of the 17th century, the period during which the most significant and long episodes of drought have been identified in the previous figures. Figure 6 visualises rain rogation levels at a monthly resolution for the first time in our geographical context. This timeline allows to analyse if drought appeared either sporadically and irregularly, or as a persistent anomaly for longer periods. In the case of prolonged drought during the rainy seasons in the region (spring and autumn), the impacts in agriculture and water supply may have been particularly severe. The results shown in Figure 6 allow to identify the years 1626-1627 as the beginning of the 1620-1630s drought episode shown in Figures 4 and 5. During the 1640s, the specific period identified spans from 1643 to 1650.

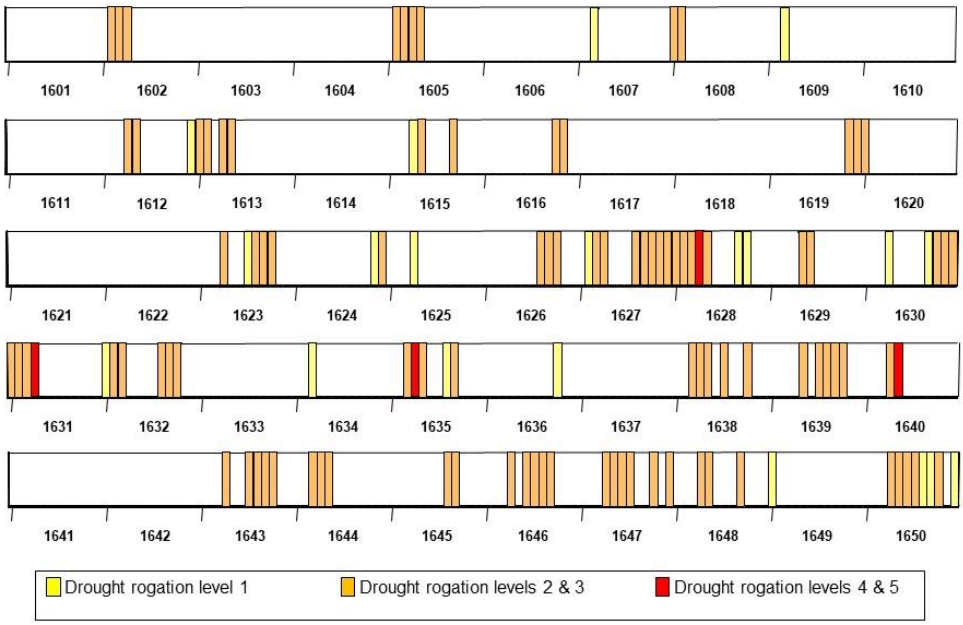


Figure 6: Monthly drought rogations levels in Barcelona, 1601-1650.

3.2 Institutional response

Throughout the period 1620 to 1650 the city government implemented a diverse range of institutional strategies to respond to drought. In the following paragraphs, we summarise these strategies, identified through our review of primary and secondary sources. Figures 7 and 8 synthesise these responses in relation to the two periods of drought identified (1620s-1630s and 1640s).

One of the main strategies developed by the city council to cope with the diminishing water flows caused by drought was the improvement and expansion of the urban water supply sources. During the 17th century, the water supplied to Barcelona's fountains came from several underground drainage canals originating in the hills surrounding the city. These structures, known as *mines d'aigua* ("water mines") in Catalan, were common in all the Mediterranean and originated in the medieval *qanats* established by Muslim settlers (Guàrdia, 2011; Custodio, 2012). On several occasions during our period of study water flows coming from these sources decreased significantly, triggering efforts from the Consell de Cent to improve and expand old *qanats* and to open new ones. Between 1627 and 1629, the city water officer built a new *qanat* that provided a significant increase in the waters delivered to Barcelona (Perelló Ferrer 1996: 126-127). During the second half of the 1640s the Consell de Cent approved the construction of a new *qanat* in Pedralbes (Perelló Ferrer 1996:129).

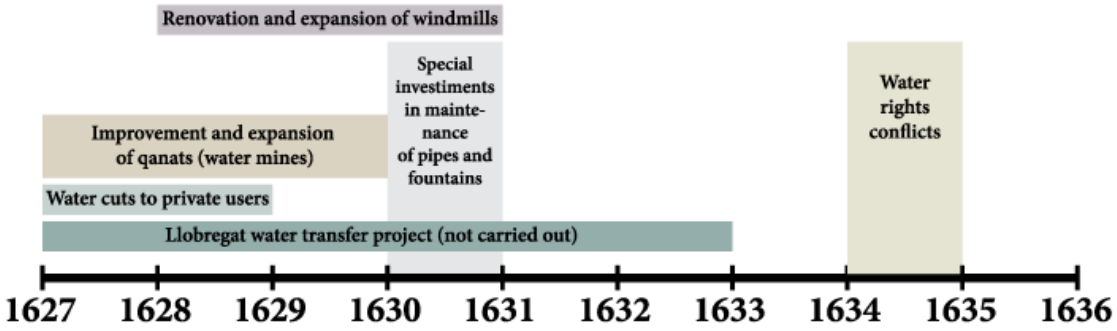


Figure 7: Strategies of institutional response to drought (1627-1636). Source: The authors.

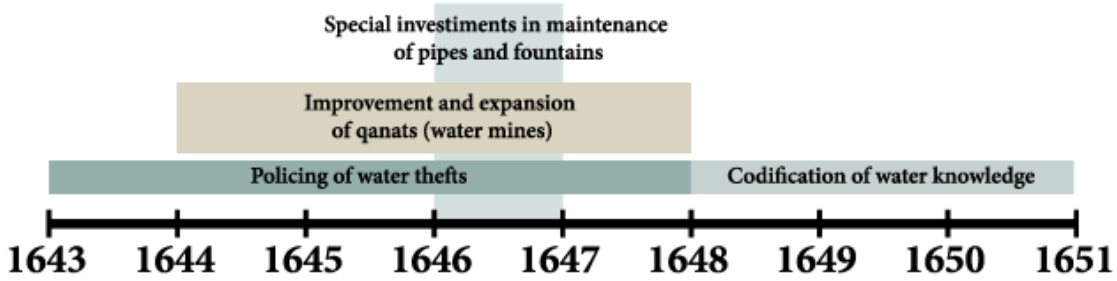


Figure 8: Strategies of institutional response to drought (1643-1650). Source: The authors.

Other attempts to diversify the water sources of the city were more ambitious. In 1627 the city government proposed to build an open water canal (approximately 12 km long) connecting the river Llobregat to the city. The Consell de Cent regarded the Llobregat waters as the "universal solution" to the problem of water supply, and published a pamphlet detailing the many advantages of the project. Several experts in water supply infrastructure came to Barcelona and worked together with the water city officer to draft a detailed proposal which was submitted to the Viceroy and eventually to the Spanish King (AS3). King Philip IV showed interest in the project, but also concerns about the landowners affected (Voltes Bou 1967: 58-59). In 1633 the project made a comeback, when the city officers called water supply experts to resume the work on the canal and even started marking it on the ground (AS4). However, the Royal Privilege needed was not obtained (AS5: 137, 154-155) and the project did not go ahead (Voltes Bou, 1967:59-60; Perelló Ferrer, 1996:127-128).

Along with the investments devoted to expanding and diversifying the sources of water supply, the city government attempted to improve the efficiency of the existent system. In 1630-1631 it devoted substantial efforts to the conservation and maintenance of the city pipes, fixing broken sections, and cleaning those that were clogged by earth and trees. During the second half of the 1640s it also invested in the improvement of the city fountains (Voltes Bou, 1967:60; Perelló Ferrer, 1996:127-129). In moments of acute scarcity, the city government would actively police water thefts from the urban supply system and, if needed, impose restrictions to private users. The severe drought experienced during 1627 and early 1628, for instance, was the justification for the city government to cut off water supply to almost all private users in the city (Perelló Ferrer, 1996:126). In order to confront water thefts during the 1640s, the city government went as far as approving a search into all the houses close to the main pipe to find where the

water leak was or who had illegally drilled into the pipe and set a tap (AS1, chapter 22; Perelló Ferrer 1996:128) (see Figures 7 and 8).

The city government efforts to regulate water use by urban institutions and private actors sometimes created acute tensions. A remarkable example occurred during our period of study involved the Consell de Cent and the Cathedral's Chapter. In 1634, the city government's decision to cut water supply to the Cathedral triggered a major scandal. The Cathedral's Chapter excommunicated the city water officer and the members of the Consell de Cent for offending the property of the Church (AS5). Even if water flows to the Cathedral were restored after its ancient water rights were demonstrated and the excommunications were lifted after several weeks, the city government publicly reasserted itself as the "master and owner of the waters that flow to [Barcelona's] fountains" (AS7).

Extreme drought did not only cause problems in the city fountains, but also in the water mills needed to produce flour. During very dry periods, the water level in the irrigation canals might not be high enough for them to function. This situation forced the city government to transport the grain to locations farther from the city, thus increasing the associated costs and occasionally jeopardizing the city's flour supply (Simon i Tarrés 1992: 165-169). The unreliability of watermills during severe droughts was invoked by the city government in their plea to bring the waters of Llobregat river to Barcelona via a water canal. In fact, it was the reason why the city government owned two windmills outside the city walls since earlier times (AS3). However, due to the almost absence of dry periods since the 1570s, these windmills were little used and fell into disrepair. In 1628, the Consell de Cent requested their renovation along with two new windmills; five more would follow in 1629. Therefore, the city government addressed the unreliability of watermills during dry years with a great expansion of the city windmills, which grew from two to nine (450%) between 1628 and 1631 (Perelló Ferrer 1996: 286-288).

Finally, towards the end of the study period (July 8, 1648) the Consell de Cent asked the water city officer to write a book about Barcelona's water supply and the operation of the city's fountains. The Book of Fountains, written during the very dry year of 1650, provides a detailed description of the city water infrastructure, including each of the branches and sections of the city's main pipe, along with the buildings receiving water supply and the location of the water conduits and fountains (see Figure 9). The value of the knowledge compiled in the book was regarded as critical, and according to the city government's instructions, it could not leave the city government's grounds (AS2:325-326, 400).

Figure 9: The urban water supply network of Barcelona as described in the *Llibre de les Fonts*. Source: Modified from Guàrdia, 2011.

The Book of Fountains did not only provide readers with a geography of the water network elements, but also with a calendar for the system's maintenance and key historical information about water property rights and concessions to specific buildings. Moreover, it includes useful information for the reconstruction of the climate of the past. Socies' account points out the years 1626 and 1627 as the beginning of a long dry period in Barcelona. According to his testimony, the first two decades of the 17th century had been a time of water abundance, when the city government supported the expansion of the water distribution system and granted water concessions to several aristocratic houses and monasteries (AS1, chapters 65, 69, 79 and 98). All this came to an end between in 1626-1627. In Socies own words, "the abundance of waters lasted until the year 1626 (…). Already in the year 1627 came a great drought and in the fountains of the city there was a great lack of water" (AS1, chapter 65). When writing the book in 1650, Socies visited the *qanats* of Nostra Senyora del Coll and pointed out that it was the first time in his life that he saw them dry. After 30 years on his post, Socies considered that as years passed by, the flow of water in the city had been decreasing. He underlined the importance of the *qanat* construction he had led in the late 1627-1629 to keep water running in Barcelona's fountains during the driest periods (AS1, chapter 65).

4. Discussion

4.1 Drought stress and political tensions

In this section, we discuss how the unprecedented drought pulse started in 1626-1627 heightened micro and macropolitical tensions in Barcelona. By looking at three ways in which the institutional responses to drought intertwined with urban and political conflicts, we shed light on the complex interlinkages between drought, water scarcity, food supply and politics at the local and regional scale.

The impacts of the severe dry period started in 1627 went beyond Barcelona and critically disrupted food supply during the following years. By 1628, a contemporary witness stated that "the dioceses of Barcelona, Tarragona and the plain of Urgell cry of thirst" (Simon i Tarrés 1992:161-162). Between 1628 and 1631, drought and extreme climate events critically affected agriculture in Catalonia, resulting in bad crops and adding new tensions to both local and regional conflicts (Simon i Tarrés 1992:158-161). The diminishing grain supplies could have been compensated with imports from southern France and Milan, but war and plague in these regions prevented it. The Barcelona city government boosted the construction of windmills to secure the transformation of grain into flour during dry periods, when watermills were unreliable (see Figure 7). However, the agricultural impact of drought in the region reduced the availability of grain.

During the spring of 1631, the protests for the price, scarcity, and bad quality of bread in Barcelona ended up in violent riots that threatened the lives of the city government members. In response to this subsistence crisis, the Consell de Cent assumed full control of bread production, putting in place a centralized, street-by-street rationing system. In the end, a wheat cargo coming from Mallorca in May 1631 alleviated the shortage (Simon i Tarrés, 1992). However, the strategy of enforcing a centralized rationing system during scenarios of scarcity –or whenever these scenarios seemed feasible– remained in use during the following years. This is consistent with other studies that have identified rationing limited resources such as food or water (either by centralising its distribution or applying sanctions) as adaptive responses to climate variability (Grau-Satorras *et al.*, 2021).

However, the very mechanisms established to cope with subsistence crisis intertwined with power struggles, sometimes setting the scene for new conflicts. During 1633 the Barcelona city government continued to enforce control over bread production and distribution, put into practice two years earlier. The insistent warnings directed at the monasteries and the Cathedral to prevent them from producing and distributing bread suggest that these regulations were far from being followed. In this context, on the 4th of January 1634, a representative from the Consell de Cent confiscated a piece of bread that had been produced by the Cathedral, confirming that this institution was disobeying the calls from the city government (AS5). The accusations escalated rapidly, and among the reprisals approved, the city government ordered the water officer to cut off the water supply to the Cathedral. In order to enforce the food rationing mechanisms, the Consell de Cent banned access to another critical resource: water.

However, this decision triggered a major conflict. Arguing that cutting the water flow was an offense to the property of the Church, the Cathedral's Chapter excommunicated the members of the Consell de Cent and Francesc Socies. While it was bread production and distribution, not water, what had originally been the cause of the dispute, legal rights about water supply were at stake. The critical value of water in the recent severe

droughts helps explaining the reprisal chosen by the Consell and the virulent response of the Cathedral. By questioning access to water, a quarrel over bread rationing and distribution rights transformed into a major legal dispute leading to the excommunication of the city government officials. As pointed out by Grau Satorras *et al*. (2016), water conflicts could occur independently from droughts, but were certainly intensified by them. Moreover, they often reconfigured the way water rights were dealt with. In the case of Barcelona, the city government could impose restrictions over water uses to certain monasteries or private urban users, but actors like the Cathedral's Chapter actively resisted these regulations. The Cathedral's Chapter proved that its water rights went back as far as 1355, as shown by the documents kept in its archive (AS6 and AS7). Water supply to the Cathedral was restored, but in the legal dispute that followed the Consell reasserted its role as the institution responsible of maintaining and overseeing urban water supply. Mutual accusations between the Cathedral and the Consell continued for months, even if the excommunications were provisionally lifted after a few weeks (AS4:205-206; AS6, AS7, AS8, AS9).

Finally, among the diverse range of strategies launched by the city government in these years (see Figure 7) one stands out for its ambition and scale: the project to build a canal bringing the waters of Llobregat river to Barcelona. Proposed as soon as 1627, the project harmed the interests of aristocratic landowners, who opposed it consistently. The petition reached King Philip IV in the aftermath of his meeting with the representative body of Catalonia (*Corts*), held in 1626, where the King's proposal to raise an economic and human contribution from Catalonia to support the Spanish army had failed (Elliott, 1984; Parker, 2013). The situation repeated a few years later, in 1632, at a time when Barcelona received less than a third of its usual water supply (Voltes Bou 1967:59). The dialogue about the project was resumed coinciding with a new fiasco at the meeting of the Catalan *Corts* with the King. The permission and Royal Privilege from King Philip IV were never obtained, and the project came to nothing despite the advanced preparations carried out by the Consell de Cent (Perelló Ferrer, 1996:127-128). Three centuries were still to pass until the waters of Llobregat were channelled to Barcelona (Burgueño, 2008; Tello and Ostos, 2012; Saurí, March and Gorostiza, 2014).

Facing decreasing water flows, the city government project to build a canal from the Llobregat river was an ambitious attempt to increase the variety of water sources supplying the city. Diversifying the sources of critical resources is an adaptive strategy to cope with climate variability that has been identified in several contexts (Grau-Satorras *et al.*, 2021). Lacking the political support needed for a major infrastructure like the Llobregat canal, local authorities in Barcelona focused on alternative, less expensive versions of the same strategy: they built new *qanats*, expanded the old ones, and invested in the maintenance of the existing system (see Figure 7). Similarly, when watermills proved to be unreliable, the city government rapidly approved the renewal and expansion of windmills. Altogether, by diversifying water and energy sources, they increased their adaptive capacity in a time of recurrent drought.

4.2 Knowledge transmission and adaptation

Under the light of the recurring droughts experienced between 1626 and 1650 supply, the efforts of the city government to codify water knowledge into a book can be interpreted as an attempt to improve future management by collecting the knowledge of the past. Like private diaries (Adamson, 2015) or peasant family books (Torres i Sans, 2000; Grau-Satorras *et al.*, 2021), the Book of Fountains aimed at gathering and transmitting experiences to future generations. Following Grau-Satorras *et al*. (2021), its

production can be interpreted as an adaptive strategy consisting of storing information to better cope with future climate variability. However, unlike private diaries or family books produced at the household level, the Book of Fountains was an initiative of urban institutional actors that involved the whole city of Barcelona and its water sources outside the city walls.

The city government asked Socies to write a book in the summer of 1648, after a significantly dry spring and five years of recurrent droughts (see Figure 6). During these years, the water stress suffered in the city made any suspected water theft a critical matter. The aggressive approach demonstrated by the city authorities in policing water thefts between 1643 and 1648 (see Figure 8) marks an increased awareness of the importance of controlling urban water infrastructure (see the following section). The need to expand urban water flows also involved investments in new *qanats* and extraordinary funds for the maintenance of the supply network (see Figure 8). All these works required additional expenditures, because the salary paid to the water city officer included only maintenance tasks. Accordingly, the city government considered that with the assistance of a book compiling urban water knowledge the expenditure related to city fountains would decrease. The economic reasons to write the Book of Fountains were explicitly mentioned in the petition directed to Francesc Socies (AS2:325-326).

When it came to intervening in urban water infrastructure, the city government depended on the water city officer. The severe impact of droughts during the 1630s and 1640s only made these circumstances more evident. By the late 1640s, the city water officer was aging with no successor in sight and the precious knowledge he embodied was in risk of being lost. In this context, the city government saw an opportunity to intervene in the process of knowledge transmission by putting forward a proposal to write a book. Only in 1650 did Francesc Socies agree to the proposal, in exchange of receiving a salary until the end of his life (AS2:325-326). The Book of Fountains was written during the continuously dry months of 1650 (see Figure 6) which caused the loss of the harvest and made the year be known as "the year of misery" (Guàrdia, Pladevall i Font and Simon i Tarrés, 1986:105).

Perhaps key to Socies' decision to accept writing the Book of Fountains, the water officer had no direct relatives to whom pass on his knowledge and job post. Traditionally, when approaching retirement, the city water officer would ask the city government for permission to perform his duties accompanied with an assistant – usually his son or son-in-law. After working together for several years the apprentice would then replace the city water officer (Perelló Ferrer 1996:77). This father-to-son tradition of knowledge transmission was common within guilds' structures, where family and the family house were units of production (for the Catalan context, see for instance Creixell i Cabeza, 2008; Solá, 2008). Within this context, knowledge about professions was transmitted to direct relatives and to apprentices. Therefore, knowledge transmission combined a type of oblique transmission (teacher to pupil) with a vertical type (father to son, uncle to nephew) (Leonti, 2011). This mechanism of transmission could sometimes involve the creation of dynasties of the same families in the same job post, keeping knowledge away from the city government (Montaner i Martorell, 1990:177).

By requiring Socies to write a book compiling his knowledge, the city government aimed at interceding in the circuit of knowledge transmission. In other words, it aimed at putting oblique knowledge transmission under institutional control. The production of the Book of Fountains shall be contextualised within the emergence of technical and practical manuals to transmit knowledge (Eamon, 1994; Long, 2001; Cifuentes i

565 Comamala, 2006). The information stored in these manuals, however, was not meant to
566 be made "public" in the modern sense. In the case of the Book of Fountains, water
567 knowledge could not be disseminated for the sake of the institutions' own interests and
568 for security reasons. The process of knowledge transmission revealed critical details
569 about the location of water infrastructure, potentially subject to attack or disruption.
570 Secrecy around infrastructure was strategic for the survival of the city, both for external
571 circumstances –the 1630s and 1640s were marked by war and the threat of military
572 siege– and internal struggles with other city institutions such as the Cathedral's Chapter.
573 The strategic value of this knowledge explains the city government's instructions,
574 which established that the book should remain perpetually in the city government's
575 premises. This also showed an explicit intention of appropriating the knowledge
576 inherently associated to the water officer's job post, restricting the access to it to those
577 authorised by the city government.

578 Writing the Book of Fountains was about compiling the knowledge of the past, but also
579 about creating an object that could store future information. Francesc Socies demanded
580 the involvement of his readers –future water city officers– to ensure that the book
581 remained a useful tool. He asked them to record at the margins of the text any
582 intervention in the water network, thus keeping knowledge to date for future generations
583 (AS1:262). By involving future water officers into the authorship, the book aimed at
584 becoming a transgenerational endeavour, a collective heritage under the control of the
585 city government. In this way it became useful for the present as a physical object, but
586 also a perdurable, vital tool for the city's future. By obtaining a book that transmitted
587 knowledge to future managers, the city government aimed at improving the institutional
588 capacity to respond to future environmental stress, while it reduced its dependence on
589 the city water officer. Moreover, armed with the knowledge compiled in the book, the
590 city government was much better equipped to impose control over urban water users.

591

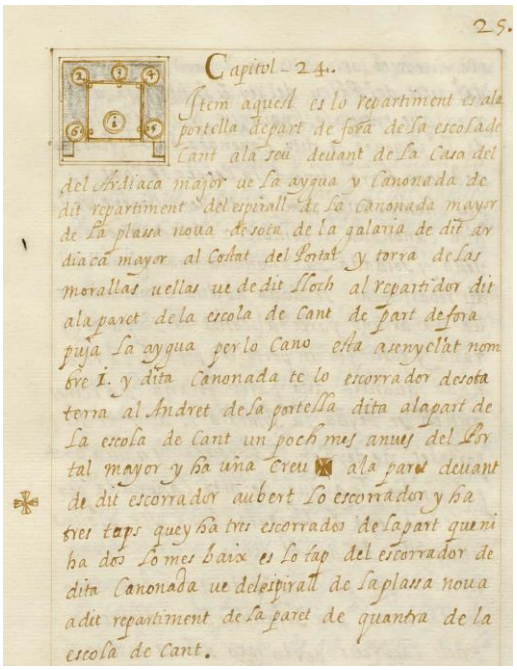
592 *4.3 Enforcing control over water infrastructure*

593 The scandal of the excommunication of the Consell de Cent and the city water officer
594 after the water cut-off to the Cathedral in 1634 came after some of the driest years
595 remembered in Barcelona (see Figures 4, 5 and 6). The city government came out from
596 this conflict with renewed awareness about the importance of enforcing control over
597 water supply, but also of monitoring information about water concessions and water
598 rights, which could help avoiding similar conflicts in the future. In line with the
599 declaration that the city was "master and owner of the waters that flow to its fountains"
600 (AS7), the city government devoted more and more attention to watch out its water
601 resources and remained wary of any violation of its water rights.

602 The production of the Book of Fountains was consistent with this strategy. The
603 ambition to write a book containing urban water knowledge and the explicit
604 requirement that it should be kept in the city government's grounds made clear the
605 Consell's determination to reinforce its position as the institution responsible for water
606 management in the city, and therefore to reaffirm its capacity to use water as a tool to
607 control urban space (AS2:325-326). In other words, enhancing the city government's
608 control over urban water flows was also one of the goals behind the codification of
609 water knowledge. The Book of Fountains was not only a way of storing information and
610 improving adaptation to future climate variability. It also meant creating a valuable tool
611 to enforce control over urban water flows and infrastructure. In terms of water property

and rights, writing was an instrumental juridical tool for the city government to reaffirm its political power.

Through the pages of the Book of Fountains, the water city officer established the itinerary of urban waters from source to tap, defining who the proprietor of this knowledge was and institutionalizing who had the power to control it. When referring to specific places in the city, he often established a symbolic relation between the written text and the urban fabric. To connect the text with the territory, Francesc Socies used a symbol –the cross– either in the text or in its margins, making its location easier to readers. These crosses written in the book refer to crosses chiselled in the stone walls of street buildings, indicating specific elements of water infrastructure hidden from view and thus binding the book pages with the urban fabric of the city. In other words: the author inscribed urban water geography into the pages of the Book of Fountains (see Figure 10).


25.

Capitol - 24.

Item aquest es lo repartiment de ala portella depart de fora de la escolade Cant ala seu deuant de la Casa del del Ardiaca major ue la aygua y Canonada de dit repartiment del espiñall de la Canonada mayor de la plaua noua desota de la galaria de dit ardiacá mayor al Codat del Portal y torra de las morallas uellas ue de dit sloch al repartidor dit ala paret de la escola de Cant de part defora puja la aygua per lo Cano esta assenyelat nom bre I. y dita Canonada te lo escorrador desota terra al Andret de la portella dita alapart de la escola de Cant un poch mes amunt del Portal mayor y ha una creu ✠ ala paret deuant de dit escorrador aubert lo escorrador y ha tres taps quey ha tres escorrados de lapart queni ha dos lo mes baix es lo tap del escorrador de dita Canonada ue delespiñall de la plaua noua adit repartiment de la paret de quantra de la escola de Cant.

Figure 10: Book of Fountains, chapter 24. On the lower left side, a cross marks a reference for the reader. The text refers to the location of the same cross in the urban fabric. Source: *Llibre de les Fonts*, Manuscrits, L-15, Arxiu Històric de la Ciutat de Barcelona (AHCB).

This intention of controlling urban space, based on the need of preserving water supply, was also explicit in Socies' instructions to future managers. In order to keep a regular water flow running in the city's fountains, the city government needed to be able to detect and solve any incident rapidly, particularly in relation to water thefts. To this end, Socies explained how he had been remaking the water network that ran through internal parts of buildings, moving pipes to their external sections to hinder any attempt to illegally tap into them. He recommended continuing with these reforms in the future, so that water infrastructure remained as much as possible within reach of the water city officer, simplifying its surveillance (AS1, chapters 26, 78 and 79).

5. Conclusions

This article examined past climate variability in the city of Barcelona (Western Mediterranean) focusing both on drought reconstruction and the institutional responses to it. First, drawing on *pro pluvia* rogations as documentary proxy data, we provided a detailed reconstruction of drought frequency and duration between the years 1521 and 1825. The years 1625-1635 register the highest drought frequency weighted index of the series (Figure 4), while the 1640s stand out in the drought duration index (Figure 5). Second, we examined the institutional strategies followed by the city government in response to drought. Among other strategies, these involved diversifying the sources of urban water supply, enforcing restrictions over water uses and compiling the city water officer's knowledge into a book. We discussed these actions considering the complex interlinkages of drought with food supply and social unrest.

By focusing on the historical analysis of drought in Barcelona, our research corroborates and expands previous work that had identified a dry period in the Western Mediterranean between 1620-1640 (Martín-Vide and Barriendos, 1995; Nicault *et al.*, 2008). Moreover, by examining the social impacts of drought in a major city of 40,000 inhabitants, we contribute to the discussion about the importance of climate variability among the factors that contributed to social unrest in Barcelona and Catalonia during the years leading to the Catalan Revolt (1640-1652). In addition, our analysis of the institutional strategies to cope with drought contribute to the scholarship on societal adaptation to climate variability (Degroot, 2018; Grau-Satorras *et al.*, 2021). In this regard, among the strategies analysed, the codification of urban water knowledge stands out for its novelty. Finally, by showing how the information collected in the Book of Fountains can be used both for reconstructing past drought events and for examining institutional adaptation, we argue that manuals of urban water management are rare but valuable documentary sources to be considered in the field of historical climatology.

Written in 1650, right at the end of the most significant drought period identified in Barcelona between 1521 and 1825, the Book of Fountains offers an authoritative voice on the perception of urban water flows: that of the city officer in charge and his thirty years of experience. His assessments of the severity of drought during the years 1626-1627 or the summer of 1650 correspond with our results of the analysis of *pro pluvia* rogations. This cross-check reinforces the authority of both documentary sources used in our research. In essence, the Book of Fountains constitutes a mechanism to store and transmit key knowledge to cope better with environmental stress. In a context marked by drought and diminishing urban water flows, the Book of Fountains was a complex form of adaptation directed at improving the efficiency of urban water management systematising historical information about repairs and maintenance, reducing expenditure, and preventing conflicts about water rights.

From this perspective, the Book of Fountains can be interpreted as an outcome of the institutional learning of three decades of coping with severe water stress. Years of local and regional tensions reinforced the city government's legal claims over the management of urban water supply. A coherent step to reassert the position of the Consell de Cent as the "master and owner of the waters that flow to [Barcelona] fountains" was to codify knowledge about urban water rights, water distribution and maintenance into a book. In times of drought, more than ever, the knowledge about the old *qanats*, pipes, deposits and fountains that formed the water supply network, together with the centenary water rights that regulated it, was key to the exercise of political

689 power. A book containing all this information was a treasure that had to be carefully
690 kept for future generations.

691

Author contribution

Santiago Gorostiza conceived this research with Maria Antònia Martí Escayol and wrote the introduction, conclusions, and sections 2.2, 3.2, 4.1 and 4.3 of the text. He made significant contributions to the rest of the article. In addition, he handled the coordination, integration, translation, and revision of texts, as well as the peer-review process.

Maria Antònia Martí Escayol conceived this research with Santiago Gorostiza and wrote section 4.2 of the text. Martí Escayol transcribed the *Llibre de les Fonts de la Ciutat de Barcelona* and made significant contributions to the introduction, section 4.1 and conclusions of the text.

Mariano Barriendos prepared the drought series for Catalonia and Barcelona, handled the database organization, statistical treatment, graphic production, and preparation of the tables and figures. Barriendos wrote the sections 2.1 and 3.1 of the text.

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Competing interests

The authors declare no competing interests.

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