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Review

The Cultural Ecohydrogeology of Mediterranean-Climate Springs: A Global Review with Case Studies

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Abstract: Cultures in Mediterranean climate zones (MCZs) around the world have long been reliant on groundwater and springs as freshwater sources. While their ecology and cultural sustainability are recognized as critically important, inter-relationships between springs and culture in MCZs have received less attention. Here we augmented a global literature review with case studies in MCZ cultural landscapes to examine the diversity and intensity of cultural and socio-economic relationships on spring ecohydrogeology. MCZs are often oriented on western and southern coasts in tectonically active landscapes which control aquifer structure, the prevalence of westerly winds, and aridity, and generally expose associated habitats and cultures to harsh afternoon sunlight. Cultural appreciation and appropriation of springs ranges widely, from their use as subsistence water supplies to their roles in profound traditions such as Greco-Roman nymphalea as well as Asian and Abrahamic spiritual cleansing and baptism. The abandonment of traditional ways of life, such as rural livestock production, for urban ones has shifted impacts on aquifers from local to regional groundwater exploitation. The commoditization of water resources for regional agricultural, industrial (e.g., mining, water bottling, geothermal resorts), and urban uses is placing ever-increasing unsustainable demands on aquifers and spring ecosystems. When the regional economic value of springs approaches or exceeds local cultural values, these irreplaceable aquatic ecosystems are often degraded, over-looked, and lost. Sustainable stewardship of springs and the aquifers that support them is a poorly recognized but central conservation challenge for modern Mediterranean societies as they face impending impacts of global climate change. Solutions to this crisis require education, societal dialogue, and improved policy and implementation.

Keywords: cultural anthropology; ecology; global review; history; hydrogeology; socio-economics; springs; water resources

1. Introduction

Human cultures develop and change in relation to the availability of limiting resources, spanning personal health and longevity and international-political societal scales [1,2]. Fresh water, particularly that delivered by springs, has been a primary limiting resource in arid regions such as those in Mediterranean climate zones (MCZs). The Mediterranean climate is characterized by landscapes with the driest season occurring during the hottest time of the year, with the peak of precipitation occurring during spring and autumn, and a high degree of seasonal and annual weather variability [3]. Upland MCZ vegetation is often characterized by evergreen sclerophyllous shrub and woodland cover [4–7]. While the ecological and cultural sustainability of MCZs and springs around the world are recognized as critically important, the inter-relationships between springs and cultural development in MCZs have only begun to receive attention, and many recent works on hydrological, cultural, and historical aspects have little to no coverage of the topic. However, such information is increasingly important, particularly in heavily populated, arid MCZs as global warming further exacerbates weather instability and fresh groundwater availability, in turn affecting safety, food production, commerce, and politics [8–12].

The concept of MCZ landscapes has been described from the individual and coupled perspectives of geography and climate and in relation to vegetation [2,13,14]. With an emphasis on vegetation, Köppen's [7] description of Mediterranean climate (Cs) was subsequently modified [15–17] and mapped [18] (Figure 1). Mediterranean climates have been subdivided into hot-, warm-, and (rare) cold-summer divisions (Csa, Csb, Csc, respectively) coupled with rainfall-dominated wet winters which have modest contributions from snow. Mediterranean climates most commonly develop on western coastlines in and around the Horse Latitudes through temperate Trade and Westerlies wind interactions between the Hadley and Ferrel cells, which create high pressure subtropical ridges. The Mediterranean Cs warm season climate has hot months with temperatures >22 °C and a mean temperature >10 °C. Cold season minimum temperatures generally range from −3 to 18 °C.

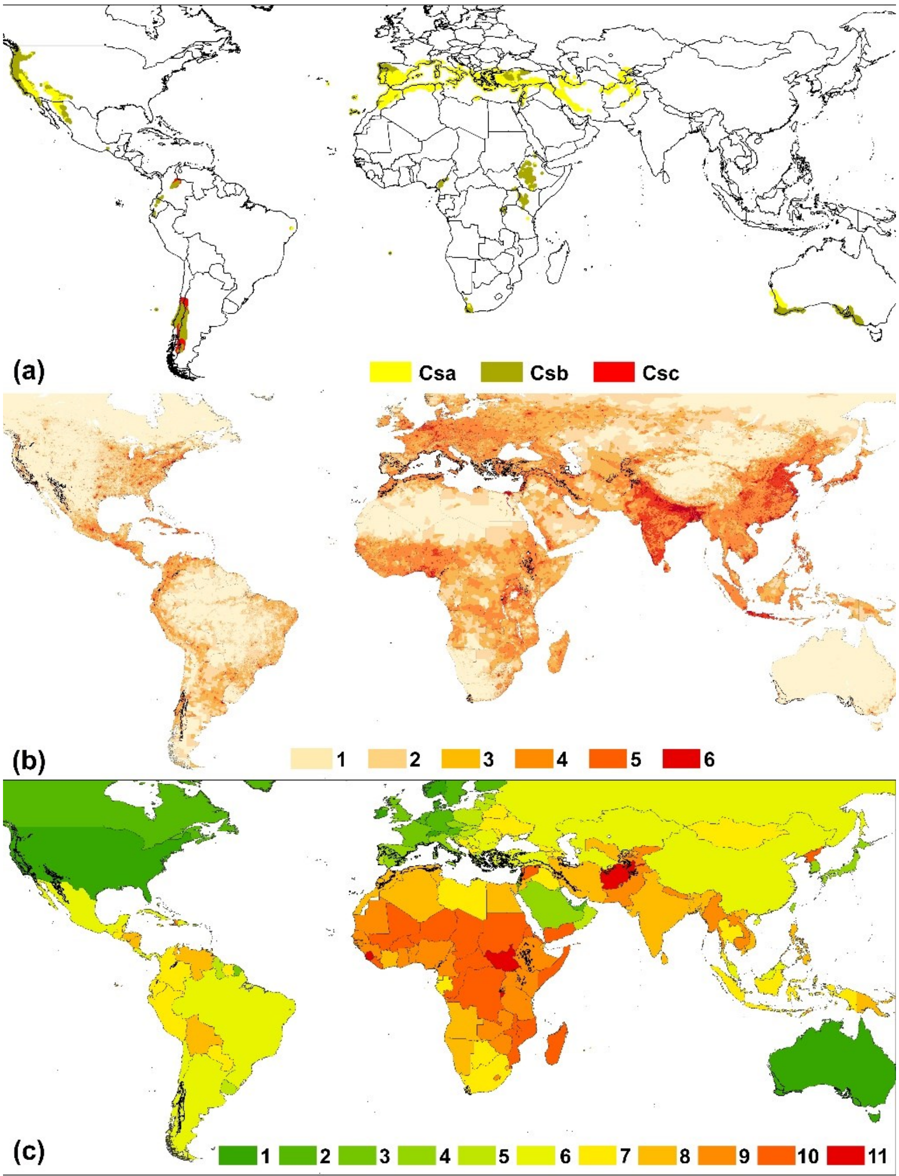


Figure 1. (**a**) Geographic areas with Mediterranean climate at a global scale. Köppen climate classification: Csa: temperate hot, dry summer; Csb: temperate warm, dry summer; Csc: temperate cold, dry summer. Data source: https://koeppen-geiger.vu-wien.ac.at/shifts.htm (accessed on 9 December 2023). (**b**) Human population density. Each grid cell is about 1 km x 1 km, colour coded to show population size. Lighter areas have fewer people. The red dots mostly show major cities. Persons/km^2: (1) <1; (2) 1–5; (3) 5–25; (4) 25–250; (5) 250–1000; (6) 1000+. In grey, the Csa, Csb, and Csc climatic areas indicated in box (a) are shown. Data source: https://sedac.ciesin.columbia.edu/mapping/viewer/ (accessed on 9 December 2023). (**c**) World map of countries by GDP per capita (nominal) for 2021: (1) >$60,000; (2) $50,000–60,000; (3) $40,000–50,000; (4) $30,000–40,000; (5) $20,000–30,000; (6) $10,000–20,000; (7) $5000–10,000; (8) $2500–5000; (9) $1000–2500; (10) $500–1000; and (11) <$500. In grey, the Csa, Csb, and Csc climatic areas as indicated in box (**a**) are shown. Data source: https://www.imf.org/en/Home and https://ourworldindata.org/grapher/gdp-per-capita-worldbank (accessed on 9 December 2023).

Springs are highly threatened ecosystems worldwide due to the coupled influences of intensifying human use and climate change [11,19,20]. The main anthropogenic impacts and threats to the world's spring ecosystems are: (a) anthropogenic habitat degradation and loss, particularly related to water abstraction and livestock management (e.g., [21,22]); (b) groundwater pollution and surface water eutrophication due to intensive agriculture practices and other causes [23,24]; and (c) climate change and associated increases in temperature and evapotranspiration [25,26], and decreased and more erratic precipitation[9]. All these impacts lead to aquifer degradation and depletion, which are of increasing importance in arid regions. Consequently, demand for freshwater will increase faster relative to its supply in MCZ regions [10], exacerbating direct and indirect impacts to human populations there.

While the analysis of the valuation and roles of springs in local and regional economics is still in its infancy, several recent studies and multiple environmental inventories indicate that when the values of regional economic uses of groundwater and springs approach or exceed local cultural uses and values, the ecological integrity of spring ecosystems and the groundwater supplies sourcing them is sacrificed [27,28].

Here we review the existing literature on cultural aspects of springs in MCZs. To augment this literature, we present multiple individual case studies of cultural history and use among MCZ landscapes and springs. The 15 case studies are geographically organized from west to east and north to south. We relate the natural characteristics of springs (their ecohydrology, sensu [29]) and associated cultural uses in the five primary regions of the global Mediterranean biome, as well as several lesser-known regions. For clarity, each case study is given its own individual introduction, methods and materials, results, and discussion sections, with all references combined into the master bibliography. We examine the literature behind the hypothesis that economic valuation leads to ecosystem degradation and assess it qualitatively through these case studies. We use the information compiled here to frame hypotheses regarding human–spring cultural interactions across social scales ranging from that of the individual to synoptic/local community, regional/political, and global spheres. Such hypotheses may help guide future research in this multifaceted field. We conclude with a description of the current and potential future cultural uses of, and threats to, Mediterranean climate springs in a changing climate.

2. Overall Methods and Materials

2.1. MCZ Geography

In the five primary temperate regions described as having a Mediterranean climate [6,30] (Figure 1), springs are relatively abundant. The Euro-African Mediterranean Basin forms the type locality for the climate and vegetation characterizing this biome, occurring broadly around the coasts and near-inland portions of the basin, except for eastern Tunisia, all of Egypt, and most of Libya [31]. The Pacific Coast of North America from southern California to central Washington and inland into portions of the northern Great Basin Desert and north-eastern Oregon have hot- to cool-summer Mediterranean climates [32]. Central southern Chile, the Western Cape Region of South Africa [33], and southwestern and southern Australia make up the remaining three regions widely recognized as Mediterranean landscapes.

Several smaller landscapes in other temperate and tropical regions also have Mediterranean climates. In the USA, the low- to middle-elevations on the southwest coast of the Big Island in Hawai'i, the Transition Valleys south of the Mogollon Rim in Arizona, the Wasatch Front in Utah and the Great Basin and Mojave deserts of North America in general, as well as portions of the north-western coasts of Mexico on both sides of the Sea of Cortez, lie in MCZs [32]. A discontinuous belt of non-coastal Mediterranean climate exists from north-western India and Pakistan into Afghanistan, northern Iraq, and Iran (e.g., [34–36]). The Canary Islands are sometimes described as having a Mediterranean climate but have been classified as a hot desert to semiarid climate (Köppen BWh and BSh). In the tropics, parts of both central western Kenya and Ethiopia are thought by some to have a Mediterranean climate, as is some of central Columbia and western Venezuela; however, we do not comment on these regions in this manuscript. Although not recognized as Mediterranean, the Galapagos Archipelago lies just south of the equator off the coast of Ecuador and has Mediterranean hot dry versus cooler moist seasons, with much variation related to oceanic current and atmospheric weather patterns [37,38].

Coastal Mediterranean climates exist due to tectonic geological processes, and occur predominantly in west-facing coastal settings with adjacent piedmonts and mountains to the east. Typical Mediterranean climate landscapes are arid due to global atmospheric and ocean circulation patterns, often with prevailing westerly winds and cool to cold ocean currents. As everywhere, MCZ human populations are often focused along and around rivers. MCZ landscapes often give rise to relatively small, short, and isolated river basins due to their tectonic processes. Consequently, many small rivers support Mediterranean populations, providing freshwater for transportation, trading, and fishing. Only three major rivers reach the sea in regions with a Mediterranean climate: the 2000 km long Columbia River drains 670,000 km^2 including several landscapes with a Mediterranean climate in the interior regions of the states of Oregon and Washington, reaching the ocean at the boundary of those two states in the Pacific Northwest of the USA; the 506 km long Rhône River drains 98,000 km^2 of the western Alps, Massif Central, and south-eastern France, reaching the Mediterranean Sea south of Arles; and the Murray-Darling River is 2560 km long, the longest in Australia, and its basin (1,061,470 km^2) occupies one-seventh of the continent. The Darling River arises in the Great Dividing Range of north-eastern New South Wales and southern Queensland, while the Murray River heads in springs in the Snowy Mountains and when joined by the Darling, flows southwest to the Southern Ocean in south-eastern Australia. In general, rivers with larger, especially trans-biome, basins tend to be less predictable and more erratic in their flooding patterns tied to the climate [39].

2.2. MCZ Springs

Mediterranean springs often emerge in proximity to coastlines, a phenomenon that may exacerbate multiple challenges to sustainable freshwater use. The already limited groundwater supplies in MCZs are easily compromised by aquifer overdraft (where use exceeds recharge) with consequent saline water incursion and land subsidence, as well as the eutrophication of surface water supplies [23,24,40]. This is particularly problematic in arid climate regions, where springs play important roles as sources of freshwater and as isolated, highly productive keystone ecosystems (sensu [41])—highly culturally and ecologically interactive habitats that sustain both autochthonous and allochthonous biological and cultural diversity [42,43]. The loss of such fertile habitats can greatly reduce regional biodiversity, ecosystem functionality, and socio-cultural integrity.

2.3. Analyses

We examined the extent of literature on cultural aspects of springs in MCZs. To do so, we conducted a search of the Web of Science (WoS) bibliographic literature and then screened the resulting list of references to select papers relevant to our analysis. In some regions, we refer to unpublished data regarding cultural and conservation aspects of the springs. We then arranged the bibliography geographically and selected the key words listed in each paper. We filtered these keywords to remove duplicates (e.g., "spring water" versus "springs water") and assessed their frequency, using the Pro Word Cloud app to illustrate the frequency of words appearing in the list of key words regarding main usages, management, traditions, economic and legislative aspects, and threats to these fragile ecosystems.

3. Results

3.1. Background—Mediterranean Basin Ecology and Cultural Overview

3.1.1. MCZ Vegetation

Upland MCZ vegetation is well described [12,44,45], but several additional points are worth noting. MCZs occur in topographically complex landscapes, with vegetation transitioning from coastal sclerophyllous shrublands to broad-leafed or other forest types farther inland. Sclerophylly is an adaptation to prevent moisture loss in periodically dry climates, and evergreen status likely reduces the burden of metabolic cost associated with seasonal leaf loss. In addition, waxy leaves may better protect coastal plant life from salt spray. Such adaptations are critical for plant survival, and present significant problems for many herbaceous traditional crop plants, as well as individual farmers, and agrarian societies. Elevation also plays an important role; mapping is traditionally performed in plain view, while landscapes such as mountains and canyons are decidedly three-dimensional (e.g., [46]). Temperature decreases with elevation through adiabatic atmospheric pressure reduction, while humidity and precipitation generally increase with elevation. Depending on the configuration of the coastal mountains, such topographic effects often exert profound impacts on agricultural practices. Lastly, MCZs often occur on western coastlines and are exposed to afternoon sunlight, an aspect effect that exposes vegetation, including crops, to harsh thermal and solar radiation stress. This added stress may favour or evolutionarily promote reduction in leaf area, increased sclerophylly, and succulent growth forms (e.g., [47]).

3.1.2. MCZ Aquatic Freshwater Habitats

Perennial groundwater-fed springs and streams in MCZs are recognized as unique ecosystems, often hosting algal, macroinvertebrate, and fish species with strongly seasonal life history traits [12,48–51]. Pascual et al. (this article) and [52] described the biodiversity of 10 springs in the karstic terrains of the Montsant Massif south of the Catalan pre-coastal ranges in the north-eastern Iberian Peninsula, and a further 10 springs in the Serra de Tramuntana Range on the island of Mallorca, reporting 500 and 363 species, respectively, of macroalgae, diatoms, bryophytes, cormophytes, aquatic invertebrates, and vertebrates. These springs were regarded as outstanding biodiversity hotspots. Similarity analysis among springs revealed only a low number of shared taxa, suggesting that each spring contains a unique biological assemblage that cumulatively greatly enhances regional biodiversity. Gasith and Resh [53] described seasonal shifts in controlling variables among aquatic MCZ faunal assemblages, with physical factors such as flooding dominating assemblage structure and function during wet periods, and biotic factors like competition and predation dominating during dry periods. The relative contributions of allochthonous versus autochthonous processes also may exhibit bimodal seasonal changes that differ from streams in non-MCZs. Studies of the Eel River in California by Power et al. [54] corroborated those patterns, adding the characteristic of seasonal variability in productivity. Seasonal aridity can also reduce and disrupt habitat connectivity, and upland aridity can result in patterns of isolation that may increase the evolution of endemism in streams [54,55] and in springs (e.g., [56]). In contrast, Montezuma Well springs in the small MCZ strip mapped in central Arizona emerges from a 13,300-year flow path with constant temperature and with naturally high concentrations of calcium carbonate and arsenic-rich water [57,58].

Riparian plant assemblages surrounding springs and streams in MCZs differ from classic Mediterranean vegetation. Profuse, non-sclerophyllous, broad-leafed, deciduous herbaceous, shrub, and tree growth can co-occur in such environments, and when exploited by farmers, many non-sclerophyllous agricultural plant species may occur as well [58]. Such habitats are often small, narrow, or otherwise limited in detectability on coarse-scale remote sensing vegetation maps. With permanent water availability, vegetation in such settings often does not meet the restriction normally imposed by dry-summer climate conditions. Where occupied, intensively used, or created by humans, such springs and springbrook riparian zones are often described as "oases" (e.g., [58]). Over millennia, the anthropogenic use of such habitats has included the manipulation and consumption of water for drinking, crop-based agriculture, livestock production, fish hatcheries, and abstracted export to other regions, including urban areas.

3.2. Cultural Anthropology

3.2.1. Palaeontology and History

Springs in many MCZs have been used by humans throughout late Neogene evolution and cultural history. Archaeological evidence commonly supports the presence of hunting camps at springs, as hunter and gatherer societies probably used springs not for dwelling, but as sites at which to ambush prey. A deep history of human presence at springs was shown in Cuthbert and Ashley's [59] paleo-reconstruction of Olduvai Gorge in Tanzania. They indicated that early hominin populations were closely bound to springs, perhaps retreating to them during periods of drought. As cultures became agrarian, settlement began to occur at larger perennial water sources, including large springs, rivers and lakes. Agricultural societies used those water supplies for irrigation, acquisition of aquatic food resources, and transportation. Subsequent settlements, states, empires, and dynasties have arisen in relation to technological advances in water supplies management and disappear when those water supply management strategies fail [2,60].

The first human settlements and ancient civilizations were closely linked to freshwater availability, which is essential for the establishment and existence of social organization, but also has been important in the religious beliefs of ancient populations related to the magical and healing properties of water. The scientific literature is replete with examples of these strong connections to water: the ancient cities Corinth (Greece), Rhodes (Aegean Island), Priene (Türkiye), and Syracuse (Sicily) were sites where the availability of high-quality karstic waters allowed the development of high-density urban centres [2,61]. The ancient population of the Apuli, which in pre-Roman times inhabited the central-northern part of the Italian region of Puglia, as well as other early settlements in the Mediterranean Basin, were similarly supported by karstic water supplies [62]. Groundwater was a critical focus of life for the ancient Greeks. The establishment of an *apoikiai* (colony; e.g., Pithecusae) first required a sufficient supply of freshwater, and springs represented both functional and symbolic connections and determinants of cultural identity [63].

From the writings and archaeological studies of these cultures, we learn about ancient cultural relationships with springs and groundwater, as well as important lessons in water supplies and quality management and technology. For example, the study of Greek and Roman hydraulic and purification systems has provided fresh insight into water management in the face of globalization [1,64]. Contemporary indigenous cultures in arid regions on all inhabited continents throughout the world possess deep knowledge of the use of springs, and most revere springs for health, spiritual, and recreative aspects. In Türkiye, the cultural importance of springs is evident at fountains that are still today an important part of both the aesthetic and functional integration of urban spaces and public life [65].

Historic literature confirms the cultural and socio-economic significance of springs and provides insight into ancient lifestyles and behaviours. Archaeological evidence reveals the development of *qanat* since the Classical period of ancient Greece. Minoan hydrologists and engineers created long underground qanats (or aqueducts) to supply palaces and settlements with water in eastern Crete from 3200–1100 BCE [1]. Qanat-aqueduct technology was also employed to direct water from the Gihon Spring through the Siloam Tunnel into the city of Jerusalem in the early 7th century BCE. Similar conveyances were developed by the Persians in the middle of 1st Millennium BCE, and the technology subsequently spread towards the Arabian Peninsula and Egypt [66]. Constructed in 140 BCE, the Hadrianic Aqueduct provided spring water to Athen's residents for the following millennium. Romans constructed advanced surface aqueducts from 312 BCE–ca. 300 CE to provide abundant freshwater to urban centres for drinking and bathing. Subsequently, the Ottoman Empire reintroduced large aqueducts to supply their urban centres with spring water for religious and social needs [64]. For example, the city of Safranbolu in Türkiye is famous for its abundant water resources and pool rooms, which serve as examples of the spatial use of water in traditional residential architecture [67]. From the times of the Pharaohs to the Persian dynasties, and from the Greek to Roman periods, ancient literature is replete with examples of the practical and cultural significance springs held for these populations. It can be difficult to distinguish artesian springs from drilled boreholes into the Nubian Sandstone aquifer in Egypt's Western Desert [68]. All these examples of hydrogeological technologies and water management practices are relevant to our understanding of the cultural role of springs in both ancient and modern societies in Mediterranean climates. Because many of the springs have ancient histories, it can be difficult to distinguish natural springs from those that have been augmented by drilling and channelling.

3.2.2. Practical Uses and Threats

Among the most valued of waters, springs are often specially regarded as essential sources of clean drinking water (e.g., [1]). Innumerable farms, ranches, and settlements around the world have been founded on springs, and at least a quarter of the world's population now relies on groundwater. A surprising number of large cities, including at least five European capitals, rely on springs for potable water, and much of the river water used in other urban centres is derived from groundwater. For example, the Colorado River in the southwestern USA is 53% groundwater, and most of the river's flow is abstracted from its channel to provide freshwater for MCZ southern California coastal cities, including Los Angeles and San Diego [69]. Many aquifers in Mediterranean seasonally-arid environments contain ancient groundwater and have low recharge capacity due to limited precipitation, high levels of evapotranspiration, slow infiltration rates, and poorly informed land use practices. This means that aquifers in many contemporary Mediterranean landscapes may not recharge in human timeframes and are therefore subject to increasing anthropogenic stress due to extraction, export, pollution, and antiquated supply systems. As a consequence, many and some large, historically important MCZ springs with long eco-sociological histories have been depleted, and many aquifers are threatened by overdraft.

3.2.3. Religion

The religious aspects of springs are highly culturally significant, including myths, symbolism, rituals, and buildings. Geva [70] describes in detail the sacred architecture associated with reverence for water throughout human history. The ancient Greeks celebrated the vital purificatory and therapeutic roles of natural springs through ritual practices in sanctuaries with oracular functions. In these ceremonies, springs were venerated as direct connections to the chthonic realm [71]. Stymphalos, famed for Herakles' sixth labour (the killing of the Stymphalian birds) and its association with Artemis, had a rich "geomythology" with a fountain-house to venerate the role of springs as the Greek city's foundation and sustainability [72]. The Amphiareion near Oropos in Greece was an inflow clepsydra (water clock), likely constructed in the 4th century BCE. It is unusual and very peculiar because time was measured there by the rate of filling of its large cistern from a sacred spring located just to the southeast [73,74]. The site was used for the reception of divine information. After having thrown coins into the spring, believers were directed to a special sleeping gallery where they could receive divine guidance regarding therapy for their illness or solutions to other problems. The Temple of Apollo and the prophetic powers of Pythia, the woman of the Delphic Oracle, played pivotal roles in western geopolitics from the 8th century BCE to the 4th century CE [75,76]. Overall, the role of springs in all cultures of the Mediterranean Basin has been one with long and important history. Ancient beliefs, traditions, infrastructure (e.g., the Roman and Ottoman aqueducts), and other aesthetic and functional aspects of springs were modified over time, with some still in contemporary use. In the following case studies, many of these connections become apparent.

3.3. MCZ Case Studies

3.3.1. Mediterranean Basin: Iberian Peninsula

Archaeology

When humans abandoned their hunter-gatherer behaviour and established small settlements, they chose places with easy access to water. In MCZs, these places were often associated with springs. The importance of springs is especially strong in karst regions where, due to the permeable nature of the carbonate bedrock (with its abundant pores, fissures, and fractures), surface water is scarce during long periods of the year and springs may be the few places to access fresh water. It is therefore likely that ancient people, like modern societies, heavily depended on these springs.

The importance of springs in the establishment of human prehistoric communities has been demonstrated across the Iberian Peninsula. The karst springs of the Malaga coast played a crucial role for the rapid Mesolithic–Neolithic transition in the southern Iberian Peninsula [77].

In the western region of the Iberian Peninsula, archaeological findings from prehistoric and Roman times reveal the use of spring water for medicinal or recreational purposes [78]. In pre-Roman times, mineral springs were used at temporary structures built for this purpose; votive inscriptions have been preserved in different sites [79]. Likewise, in the Sicó massif, which covers an area of 430 km^2 in the Portuguese western Mesocenozoic rim, relics that testify to human presence during the Mesolithic period are still visible, with many megalithic monuments scattered over the landscape [80]. Paleolithic artefacts and a Neolithic collective grave were found in inactive springs associated with Ourão spring [81].

Other examples can be found in the eastern Iberian Peninsula, in the case of Caldes de Montbui [82] where the oldest remains date from the Neolithic period (4500–2200 BCE). Similarly, some of the first settlers in the region are thought to have been associated with the Empoadors spring at the foot of the Iberian wall of Montgròs in the Montseny Natural Park [83].

In the south and southwest of the Iberian Peninsula, abundant remains have been found in the Ibero-Roman settlement of Fuente de la Loma, in Murcia [84], or in Fuente de la Silla del Papa, in Tarifa [85].

Springs were also of great importance to ancient routes of travel and communication. On the Vía de la Plata (Extremadura), already used in the Tartessian era and later by the Romans, many springs are located next to the route [86], suggesting their use by travellers.

During the Roman period, the need for water increased with the growth of cities, so that this resource was increasingly imported from more distant regions. In the western edge of the Iberian Peninsula in Portugal, one of the most important springs during this period was Alcabideque spring, which gave name to the locality where it is located (Alcabideque, from the Latin *caput aquae* that means "head of the water"). Alcabideque spring (annual discharge: 16 million m^3) contributed to the establishment of the nearby city of Conímbriga, which became one of the most important Roman cities in the occidental limit of the Roman Empire [81]. One can still see the hydraulic system built by the Romans between 20–15 BCE, which includes a reservoir where spring water was retained, and a tower that covered a settling well (*Castellum* of Alcabideque). Spring water was carried to the city of Conímbriga, 3 km away, by an aqueduct which was buried for most of its length. A testimony to Roman engineering, the *Castellum* of Alcabideque is classified as a National Monument, which highlights its historical and cultural interest (Figure 2A). On the opposite side of the Iberian Peninsula, an aqueduct conducted the water from springs—as well as nearby rivers—towards Tarraco [87]. Other large hydraulic engineering works built by Romans include the water mines near Seville [88,89].

Figure 2. Karst springs in the Sicó karst massif (central Portugal): (**A**) Alcabideque spring (1, reservoir; 2, *Castellum* of Alcabideque; 3, community place to wash clothes; 4, picnic area); (**B**) Olhos de Água do Anços spring (1, spring outflows); (**C**,**D**) Ansião spring (1, spring outflows; 2, urban park); (**E**) Alvorge spring (1, spring outflow; 2, access for vehicles; 3, community place to wash clothes; 4, picnic area); (**F**) Arrifana spring (1, spring outflows; 2, religious symbols; 3, community place to wash clothes; 4, picnic area). Photo credit: V. Ferreira.

Thermal Springs and Spas

The Roman expansion also brought forth other uses for springs. Spring water, especially that of thermal outflows, had already been used by Greco-Latin cultures for healing and social purposes [90]. The expansion of the Roman Empire generalized the use of baths throughout the conquered territory, including Hispania [91]. In the Iberian Peninsula, there are records of about 50 archaeological sites related to spas, with a clear predominance of sulphurous or hyperthermal waters [92]. The geological and topographical context of the indigenous roads, which were later improved by the Romans, meant that these mineral-medicinal springs were used to create enclaves and meeting points for local populations [93]. In the northwest of the Peninsula, where thermal springs abound, there are 4 Aquae sites: *Aquae Celenae* (Caldas de Reis), *Aquae Querquennae* (Baños de Bande) (Figure

3B), *Aquae Oreginae* (Rio Caldo, Lobios) (Figure 3A), and *Aquae Flaviae* (Chaves), all of them road mansions in the territory of *Gallaecia*.

Figure 3. (**A**) *Aquae Oreginae* (Lobios), Phot credit: C. Delgado; (**B**) *Aquae Flaviae* (Chaves). Photo credit: C. Delgado.

A total of 39 springs in ancient *Gallaecia* are of particular interest for their historical-archaeological context and associated buildings (e.g., Lugo, Ourense, Carballo, Chaves, and Caldas das Taipas).[79]. It was also in Roman times (1st century BCE–1st century CE) when an urban centre was constructed around the thermal springs of Caldes de Malavella and Caldes de Montbui. The Roman baths of the latter are the best-preserved of the Iberian Peninsula, although what remains is a small part of what must have been a huge thermal complex where different activities related to hygiene, leisure, and therapeutic treatments were developed. Overall, up to 152 springs used during Roman times have been identified in the Iberian Peninsula [93,94], with at least 132 used as spas (Figure 4).

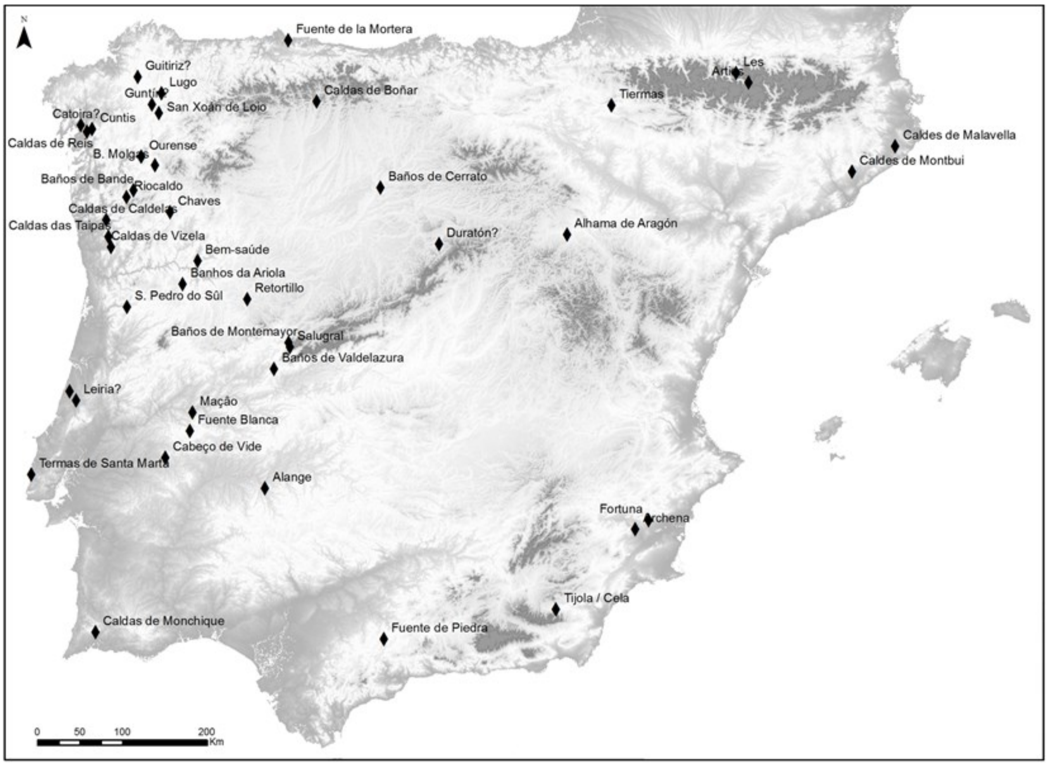


Figure 4. Main Roman spas in the Iberian Peninsula. Reproduced from Silvia Gonzalez Soutelo and Gonzalo Matilla Séiquer (2017), Inventario y revisión de los principales enclaves de aguas minero-medicinales en Hispania. Un estado de la cuestión, in G. Matilla Séiquer and S. González Soutelo (eds.), Termalismo antiguo en Hispania: un análisis del tejido balneario en época romana y tardo-rromana en la península ibérica, Anejos de Archivo Español de Arqueología, 78, 495-602. Fundación Séneca: 1507. https://fseneca.es/web/elaborado-el-mapa-de-los-balnearios-romanos-de-la-peninsula (accessed on 10 January 2024).

Many of the Roman springs were later used during the Muslim occupation of the Iberian Peninsula by the Arabs, who introduced new techniques for mining and conducting the water. In some areas, the number of springs significantly increased during Muslim rule (see the Section 3.3.3 in this article). This legacy has survived to present times, as suggested by the Arabic prefix "Al" which remains in the names of several springs across the Iberian Peninsula: Fonte da Ribeira de Alcalamouque, Fonte do Alvorge (Figure 2E), and Fonte de Alcabideque (Figure 2A) (Portugal); Fuente Alfila, Fuente Alhama, and Fuente Alquería (Andalucía); Fuente Altorruza, Fuente Almesaña, and Fuente de Almazara (la Rioja); or Font d'Albió, Font d'Alsamora, and Font de l'Albergada (Catalonia).

Most spas of Roman origin fell into disuse over the centuries but underwent a revival around the 19th century [95,96]. The rise of the middle class favoured the proliferation of establishments associated with sources of mineral-medicinal waters that offered supposed health benefits. More than 250 baths have been documented in Spanish territory, with a great diversity of mineralogical composition, and documented to treat different ailments (e.g., skin conditions, rheumatism, and paralysis) for which they are indicated for therapeutic use (Section 3.3.2).

A good example of this phenomenon is the Roman bath of Trillo (*thermida* in Roman times) in Guadalajara, Spain. Both the Romans and the Arabs made use of these thermal baths, but in later centuries they fell into disuse and were abandoned. The recovery of the spa did not take place until the end of the 18th century, under the reign of Charles III. Pipelines were channelled, fountains were repaired, and a chemical study of the water was commissioned. By 1777, the so-called Hydrological Hospital had been established, an institution to treat various ailments, notably arthritis and rheumatism. The institution gradually expanded and became a place of socialisation for the wealthy. At the beginning of the 20th century, after a period of decay, it became a sanatorium and leprosarium ([97] and references therein). Only recently the thermal baths have been restored yet again, part of a sumptuous spa. Another example is the complex of Caldes de Montbui (Catalonia) which, despite its enormous importance during the Roman period, fell into disuse and deteriorated over several centuries. It was not until the late 18th century, due to booming interest in mineral-medicinal waters, that most of the baths and buildings were restored. Notably, the waters that flow in Caldes de Montbui are of deep geological origin and have a temperature of 74 °C, making it one of the hottest springs in Europe. In Portugal, Arrifana hot baths, two small springs with water temperature ~20 °C in Arrifana village, were used to treat skin conditions, intestinal problems, and rheumatism from the end of the 19th and the middle of the 20th century [81]. However, the therapeutic use of karst spring water in this region has declined, likely due to the development of thermal baths in nearby regions.

At the end of the 20th century, some establishments modernized and began to offer a broader range of natural therapies [98,99] in addition to the traditional curative use of the water itself [100]. However, others lost a large part of their visitors, often leading to their closure [95]. Nowadays, stays in this type of establishment become a social event whose objectives also include seeking rest and tranquillity away from the hustle and bustle of big cities.

Residential, Livestock, Agricultural, and Leisure Uses

Besides the historical evolution of spas and health resorts, springs have always been intensively used for other purposes by people living in Mediterranean regions due to an overall lack of water. This is why small towns in rural areas, and farms that hosted one or several related families, traditionally settled close to rivers or, when those were lacking, springs. In dryer regions, people had to rely either on wells or water mines, horizontal wells which increase the transmittance of the aquifer and allow the release of spring water through an artificial outlet. This water serves many purposes, both residential and agricultural. Some high discharge springs are used to irrigate crop fields and, in some instances, to provide drinking water to urban centres: this is the case of Ourão spring (annual discharge: 25 million m^3), which supplies water for domestic use to the Pombal and Soure municipalities, even powering five water mills during the 19th century [81].

In small towns and villages, some of these springs were also used as washing places (Figure 5) where people gathered to wash clothes and other household items, but also to talk and comment on events occurring in the town or the surrounding area (Section 3.3.2). The social importance that washing places held is well exemplified by some expressions, still deeply rooted in various Latin languages, such as "wash the dirty linen" (e.g., in Spanish *lavar los trapos sucios*) in relation to criticising or sharing other people's intimacies in public, or "clothes are on the line" as a warning that one could not speak in front of a certain person, or a child. Some of these washing places are still preserved or have been restored (Figure 6), but many others have been destroyed and the space repurposed.

Nowadays, some of the most common uses of springs are related to leisure or recreation. In mountainous regions, springs provide water for hikers and travellers. Some high discharge springs have become tourist attractions: such is the case of the Olhos de Água do Anços spring (Figure 2B), which is used in summer for bathing and boating. Also, some karst springs have speleological interest because of their complex system of underground galleries and caves: the Olhos de Água do Anços spring and Olhos de Água de Ansião spring (Figure 2C,D) have been explored by speleological diving up to 63 m and 70 m deep, respectively. The galleries associated with the Olhos de Água do Dueça spring were first explored by divers in 2003 and 2004 for 980 m and Olho do Tordo spring is also known to have 150 m of galleries [81].

On the other hand, some people still go to natural springs to collect water to drink at home. The springs used for that purpose typically have soft water (low electric conductivity) and high rates of water flow, often laying close to roads which allow visitors to park their cars and load them with water bottles. On the other end of the spectrum in terms of water chemistry, we find naturally occurring sparkling water springs. The water of these springs often also contains high concentrations of other elements such as sodium, iron, or manganese, and has been believed to have healing properties for a wide array of diseases since the mid-19th century (see above in this section), even though high concentrations of some of these elements (e.g., manganese) is now known to be harmful.

Figure 5. Women laundresses in the city of Santiago de Compostela. Reproduced from https://www.parquefluvialdesantiago.org/es/las-lavanderas-y-el-oficio-de-lavar/ (accessed on 2 December 2023).

Biodiversity Hotspots

In the last decades, several scientists have highlighted the importance of springs as biodiversity reservoirs. Providing a biotope with permanent water and highly constant thermal settings, springs are both hot spots of biological richness and refuge for endemic and threatened species, especially in Mediterranean and other dry climates. This has been recently demonstrated for karst springs in the north-eastern Iberian Peninsula and nearby islands (Majorca) [52]. Another interesting phenomenon related to the constancy of environmental conditions in spring habitats concerns the river nerite (*Theodoxus fluviatilis*), which reaches densities as high as 9000 individuals/m^2 in the Olhos de Água do Anços spring [101]. Inhabiting these springs where water temperature is constant at ~16 °C year-round, the snails reproduce continuously, and small individuals are present throughout the year. This contrasts with the snail reproductive phenology in environments subject to seasonal fluctuations in temperature across its geographic distribution where egg capsules laid in spring hatch 2–3 months later, but those laid in late summer lie dormant until next spring, as embryonic development stops at water temperatures below 10 °C [102]. Environmental stability has also been important in the choice of springs as places to preserve endangered plant species, as for example *Vallisneria spiralis* and *Groenlandia densa* in the Arrifana spring, or even for reintroducing regionally extinct taxa as *Nymphaea alba* and *Nuphar luteum* in the same spring, in the framework of the FloraReply project (https://www.ramsar.org/sites/default/files/documents/import-ftp/COP14NR_Portugal_e.pdf, accessed on 6 November 2023).

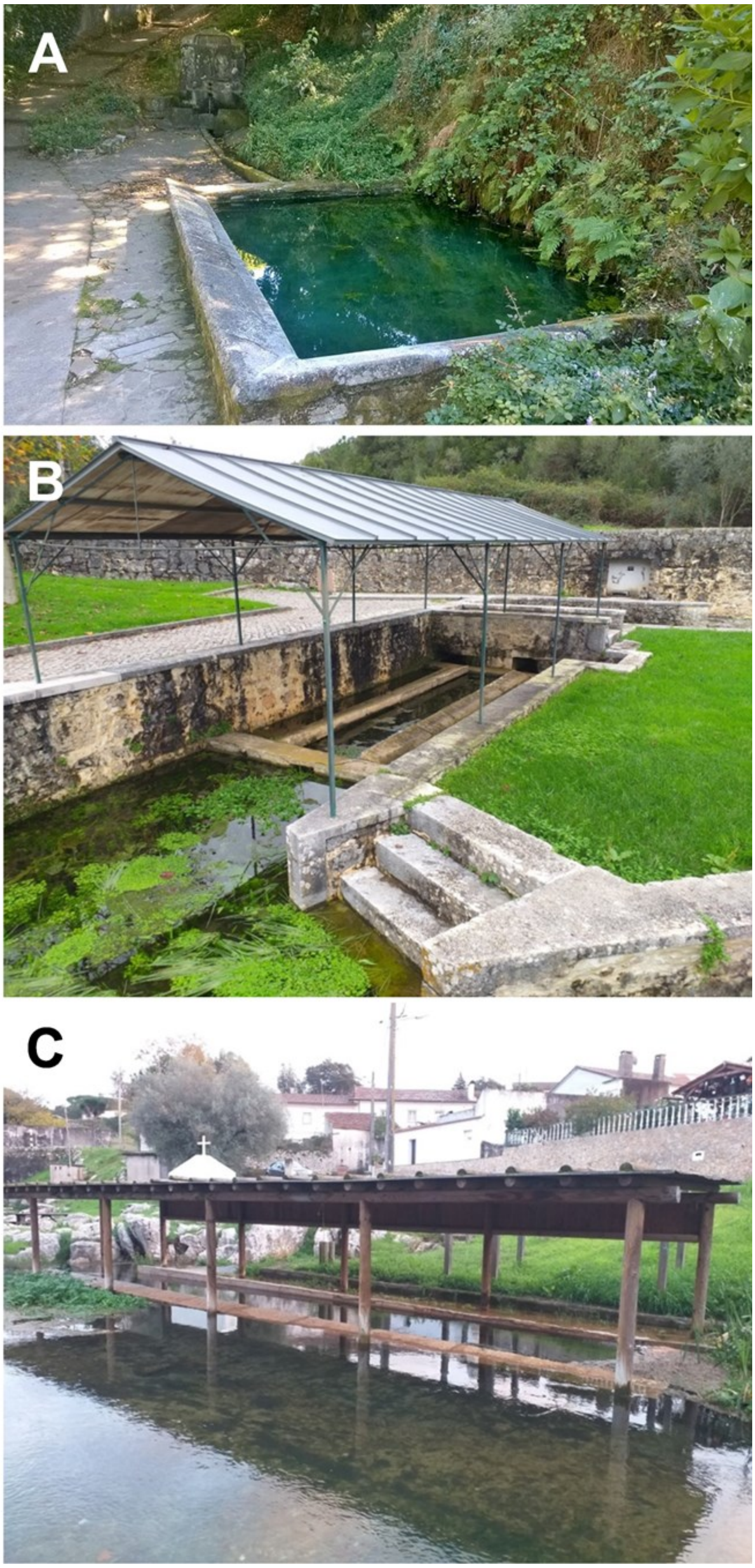


Figure 6. Community washing place associated with springs. (**A**) A Ponte Vella de Vidán spring (Galicia). Reproduced from https://www.parquefluvialdesantiago.org/es/las-lavanderas-y-el-oficio-de-lavar/ (accessed on 2 December 2023).; (**B**) Alvorge spring (Central Portugal); (**C**) Arrifana spring (Central Portugal). Photo credit: (**A**): Reproduced from https://www.parquefluvialdesantiago.org/es/las-lavanderas-y-el-oficio-de-lavar/ (accessed on 2 December 2023); (**B**,**C**): V. Ferreira.

Legends and Myths

Since springs are tightly linked to the history of cultural development, it is not surprising that they are often present in mythology. The oldest references to legends and myths about springs and their waters date back to ancient Greece and Rome. Nymphae, young maidens with divine essence, were thought to inhabit many of them (e.g., Arethusa in Ortigia, Peirene in Corinth), and the Romans celebrated an annual festival, the *Fontinalia*, dedicated to these beings [100].

In postclassical Europe, nymphae are transmuted into fairies. They remained a popular folk belief for centuries, acquiring great relevance during Romanticism when they were narrated by writers, such as Gertrudis Gómez de Avellaneda in *La ondina del lago azul* and Gustavo Adolfo Bécquer in *Los Ojos Verdes*. These works were inspired by medieval stories [103,104]. Legends and stories about *ondinas*, *damas de agua*, *lamias*, *lamiñaku*, *mouras*, *encantadas*, *dones d'aigua*, *lloronas*, and others are recounted throughout the Iberian Peninsula [104,105].

The relationship between spring-bound nymphs and humans is complex and context dependent. Sometimes it was thought that the waters protected by them have a healing nature, while in other cases it was thought that bathing in them is prohibited and carries serious consequences [104–106]. Sometimes the nymphs try to make humans fall in love with their songs, aiming to use them sexually and then destroy them. *Los ojos verdes* (The green eyes) that Fernando de Anglesola sees reflected in a spring and with which he falls in love are not those of a fairy but those of the devil in the form of a woman [107]. The deep roots of these myths have led to many toponyms based on them: Fuentidueña, Fuensanta, Fonsagrada, Fuente de la Xana, Fuente de la Lamia, etc. [108]. Later, these nymphs, fairies and *damas de agua* were Christianized into virgins, the places themselves dedicated to virgins and saints.

3.3.2. Mediterranean Basin: Spain—Montsant Massif

Introduction

Cultural relationships with springs in a karstic range in the Mediterranean Basin were reconstructed from interviews with elder residents of the Monsant Massif in the Priorat region of Tarragona, north-eastern Spain. This mountain range has a surface area of about 160 km^2 and is mostly composed of Oligocene calcareous conglomerates, although Triassic limestones, dolomites, and sandstones, as well as Carboniferous sandstones, slates, and phyllite sediments are exposed in its southern region. These geological settings give rise to a great diversity of natural springs. The region experiences pronounced droughts in the summertime, when springs become the only water sources across extensive areas.

The study area includes 13 small hamlets and villages with populations of 2 to 947 inhabitants (collectively 3077 inhabitants in 2022). The Montsant Massif was declared a Natural Park in 2002, which stimulated new scientific studies and a focus on sustainable management of its natural heritage, including its springs.

Methods

In this comprehensive socio-cultural study of Montsant Massif springs, we considered it imperative to interview residents who, due to their occupation or other activities and advanced age, could provide in-depth knowledge of the landscape and its springs. We interviewed informants from all the region's villages in the Montsant natural area except for Albarca, which at the time of this study had no inhabitants. Still, we were able to obtain published interviews with 11 residents about Albarca springs from Palomar [109]. Although we aimed for a relaxed atmosphere during our conversations, interviews were conducted in a standardized format.

Results

Informants: All informants were elderly and were, or had been farmers, and most had practiced complementary activities that gave them a deeper knowledge of the territory, particularly hunting and collecting mushrooms (Table 1, Figures 7 and 8). Bibliographic references are listed where statements were not directly obtained from conversation with the informant.

Details about the informants are provided in Table 1 and Figures 7 and 8.

Springs in the Study Area: The informants identified a large number of springs (Table 1). Taking those cited by more than one informant into account, a total of at least 398 springs were recognized in the study area (Figure 9). Considering that the surface area of the region plus the neighbouring areas of the municipal districts is about 230 km², the resulting density comes to 1.7 springs/km². However, this information regarding the region's springs is likely incomplete because the knowledge and memory of the informants is not infallible. For example, up to 10 well-known springs along hiking routes were not mentioned by any informant (e.g., [110]). Nonetheless, the informants reported springs abundance ranging between 13 (Escaladei) and 59 (Torroja del Priorat). The number of springs cited and thoroughness of accounts also varied considerably among informants.

Table 1. List of informants from the towns of the Serra de Montsant.

Village/Hamlet *	Informant	Age	Main Profession	Number of Springs Cited **
Albarca	Several (11) reported in Palomar [109]	---	---	20
Cabassers	Ramon Masip	69	farmer	23
Cornudella de Montsant	Ildefons Gomis	90	farmer	72
Escaladei	Benito Porqueres	84	farmer	13
la Bisbal de Falset	Miquel Franquet	83	farmer	22
la Figuera	Jaume Roca	78	farmer	17
la Morera de Montsant	Joaquim Figueres	65	farmer	48
	Ramon Sabaté	79	farmer	
la Vilella Alta	Josep Maria Masip	65	farmer	37
la Vilella Baixa	Eduard Juncosa	66	farmer	28
Margalef	Miquel Amill	69	farmer	28
Poboleda	Salvador Burgos	52	farmer	14
Torroja del Priorat	Joan Pàmies	70	farmer and shepherd	59
Ulldemolins	Ramon Pere	59	farmer	41

* The springs cited by each informant are not circumscribed exactly by the municipal district, but by the territory best known to the local population, which may include other municipalities and/or exclude part of their own. In the cases of Albarca and Escaladei, this applies to the old districts which have been integrated into the contemporary municipalities of Cornudella de Montsant and la Morera de Montsant, respectively. ** The number is approximate since it could not be remembered precisely in certain cases, and some informants only mention the most important springs.

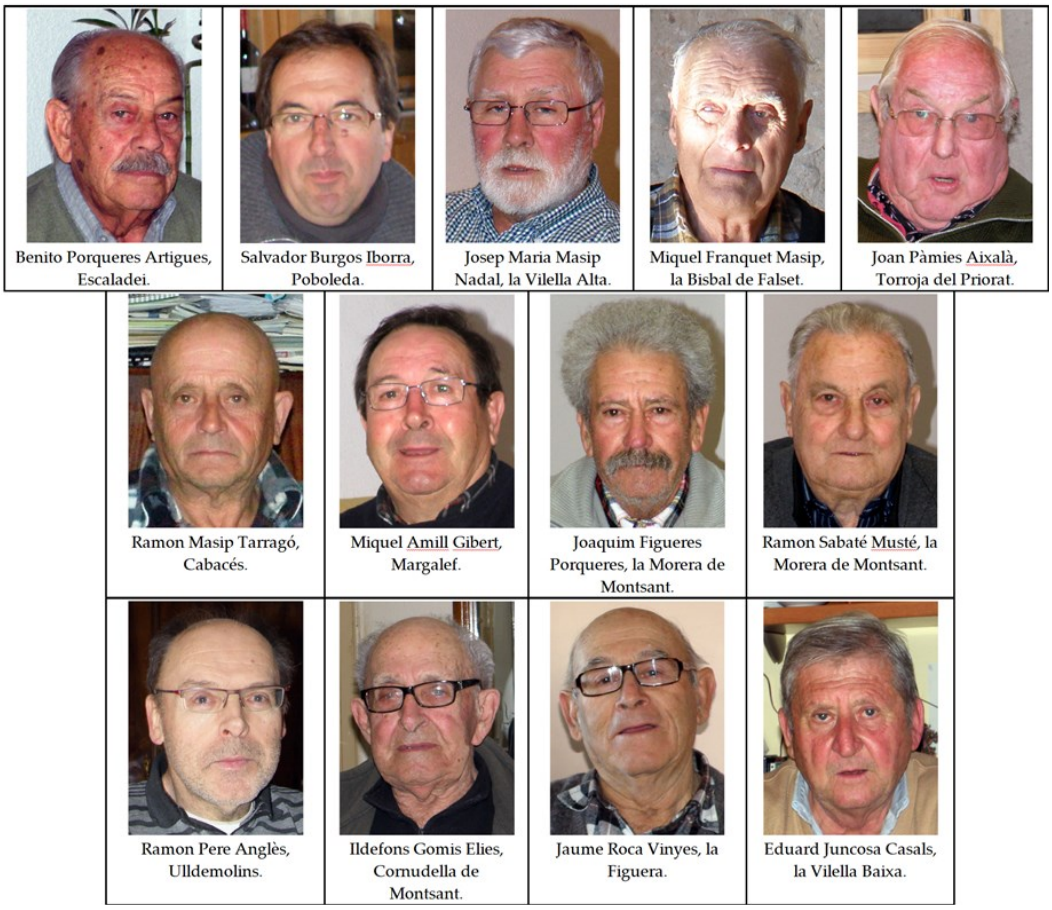


Figure 7. Portraits of the key informants taken the day they were interviewed. Consent to publish portraits was obtained from the informants, who were fully aware of the project of springs inventory and its implications, at the time of the interview (interviewed by R. Pascual). The portraits honour all the informants, especially the will and the memory of those who meanwhile deceased.

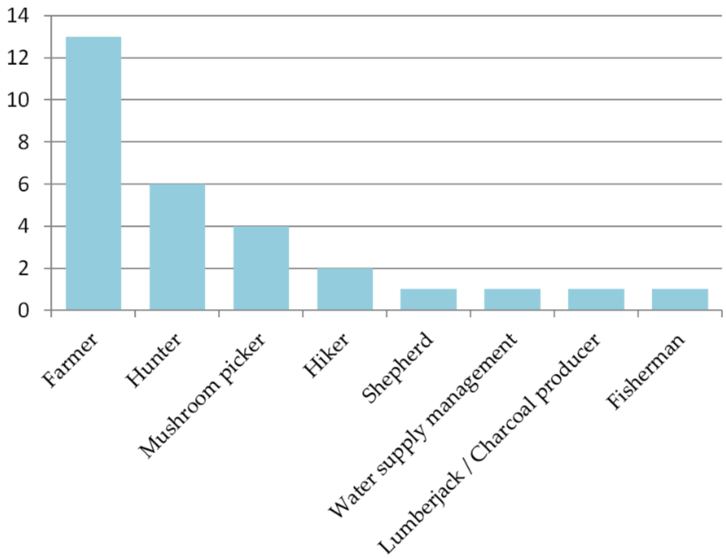


Figure 8. Professions and activities practiced by the key informants (n = 13); several activities may be attributed to a single informant.

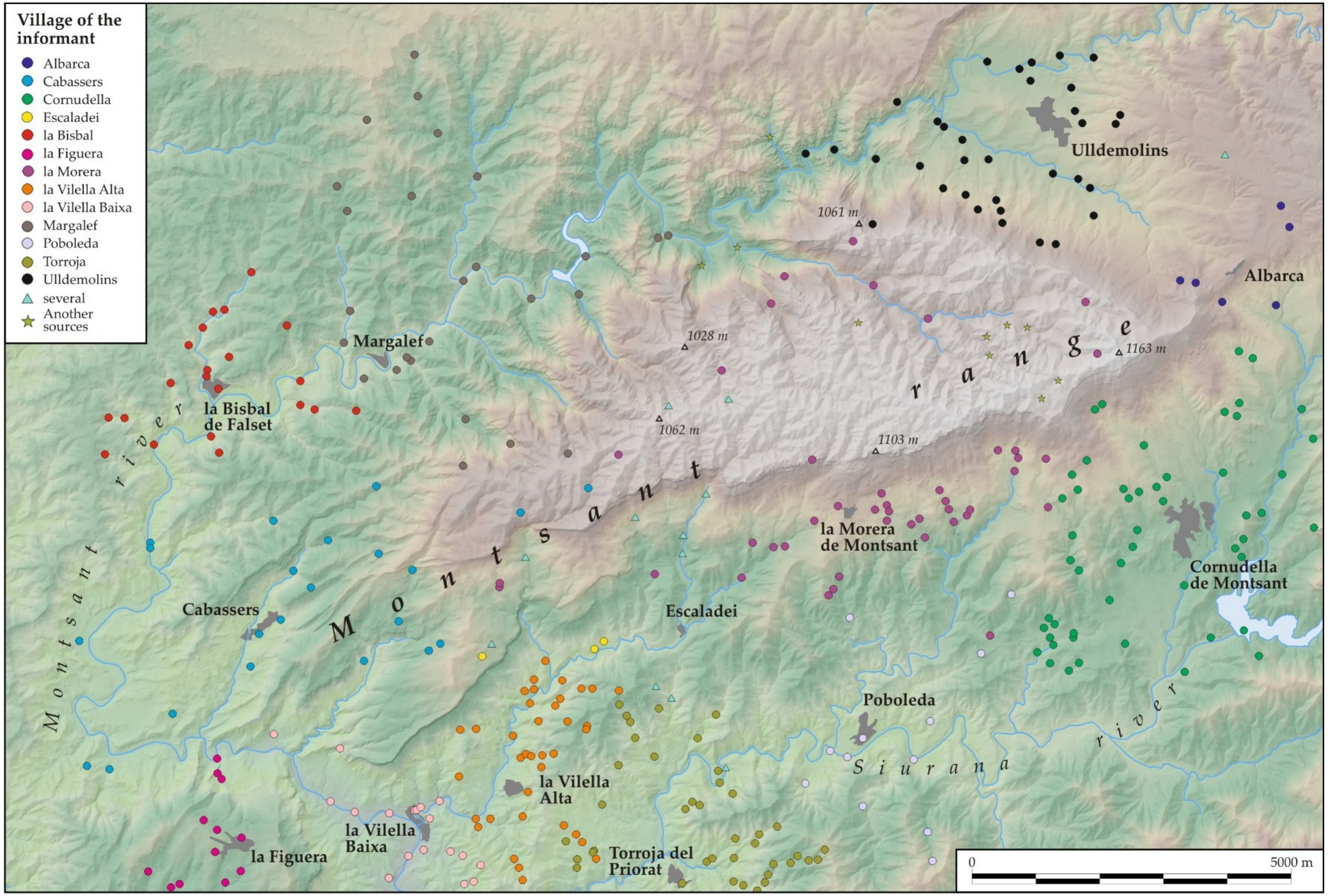


Figure 9. Location of the reported springs by the key informants per study area (coloured dots). The colour of each dot corresponds to the origin of the informant who reported it. About 50 springs reported could not be located with a minimal precision on the map.

Traditional and Current Uses: Overall, the most important uses of springs were for drinking water (both directly and through channelling to community supply networks) and for the irrigation of subsistence vegetable gardens. These uses were mentioned by almost all informants. Recreational use, although secondary, was also widespread. Other less frequent uses, mentioned in fewer than half of the villages, were for animal watering, phytosanitary treatment, balneotherapy, gatherings and celebrations, pilgrimages, washing laundry, and use in small-scale construction projects (Figure 10).

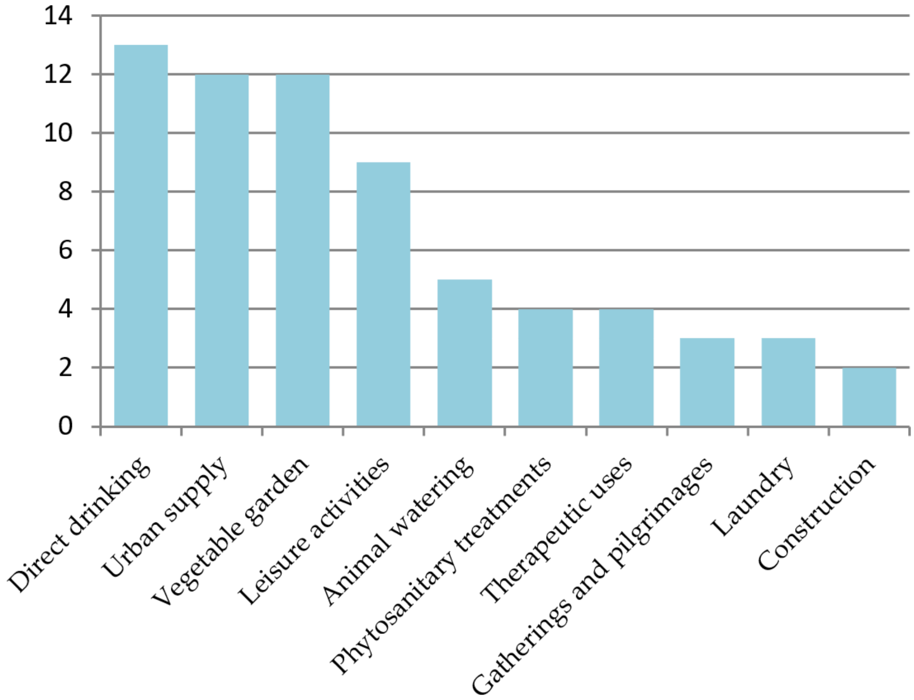


Figure 10. Number of villages where the key informants reported the listed uses and activities related to springs (n = 13); several uses and activities were reported for some villages.

All informants noted that farmers, hunters, mushroom pickers, charcoal producers, and carriers drank directly from springs. Many informants explained that most of the estates harboured springs. These springs usually had a meagre discharge but were sufficient to allow the owners to drink from them over most of the year. In Torroja del Priorat, for example, the informant estimated that more than two-thirds of estates had at least one spring. Typically, the farmer brought spring water home in earthenware containers (Poboleda, Albarca), called *gerrots*, *cànters* or *canterelles*, depending on the size of the container. Santa Llúcia spring, located in a wide, shallow cave, supplied water to the Republican army field hospital installed there during the Spanish Civil War (1936–1939). The practice of drinking water from spring outlets has declined over time but many still collect water from springs, especially in summer when urban tap water is of lower organoleptic quality (Margalef, la Figuera).

Community use remains widespread. In fact, 11 of the 13 villages are still supplied, at least partially, with water from natural springs. Only la Vilella Baixa and Torroja del Priorat are not regularly provided with spring water, although they were in past times of drought. Some villages were only provided with water from a single spring, and periods of low flow in summer resulted in rationing; the village of la Vilella Alta suffered from this situation until the 1960s. In addition to supplying the urban network, springs may be channelled to urban artificial fountains (Poboleda, Cabassers). The channelling and storage of water to guarantee its availability in the study area dates back many centuries (Escaladei). The Escaladei Charterhouse, founded at the end of the 12th century, was the first monastery of the Carthusian order on the Iberian Peninsula, and it quickly established a water supply channelled from the catchment of several springs in the valley. The same infrastructure currently supplies the village of Escaladei.

Most informants reported subsistence use of the springs for the irrigation of vegetable gardens or even of small orchards. “Spring(time) gardens” were irrigated in la Vilella Alta by temporary springs that dried up during summer droughts. In other cases, small pools associated with ephemeral springs were used to store water for irrigation through the summer (Escaladei). One of the informants reported that, among the people of the village, there was the opinion that vegetables irrigated with spring water tasted better than those irrigated with river water (Cabassers). The implementation of modern irrigation networks has reduced the importance of springs for the irrigation of gardens and orchards in some areas, but this use remains widespread in the study area.

In nine of the thirteen villages, the informants reported recreational or festive activities involving springs (Figure 11). One of the most popular was the tradition of going to certain springs on Easter Monday to eat the *Mona* (la Bisbal de Falset, Cabassers, Margalef, la Morera de Montsant, Ulldemolins, Cornudella de Montsant, and la Vilella Baixa, Torroja del Priorat), an outdoor lunch shared by numerous neighbours, at which a traditional cake, *la Mona*, is served at the end of the event (the Guenon). Although the event is less frequently celebrated today, some residents still preserve this tradition. One informant also told of the celebration of Maundy Thursday around one spring (la Vilella Alta). Additionally, it was previously common for mothers to take their children for a snack at a nearby spring (Escaladei, Cabassers, Ulldemolins, la Vilella Baixa), but this practice is also in decline. However, springs continue to be the setting for diverse recreational gatherings, lunches, baths, and other meetings among family or friends (Poboleda, la Figuera, Torroja del Priorat, and la Morera de Montsant).

Figure 11. Family gathering at Molí del Vilar Spring (**left**) and lunch at Sant Salvador Spring (**right**). Both pictures were taken in summer 1930. Photo credit: R. Pascual.

Livestock watering at springs was reported by the informants of five villages. Although pack animals, mainly mules and donkeys, formerly drank from troughs located at the entrances to villages, some springs were also used for this purpose (la Bisbal de Falset, la Morera de Montsant, Cornudella de Montsant, la Figuera). In such instances, they were equipped with a small sink (Cabassers). Pack animals had disappeared completely in most villages by the end of the 20th century and, although some wineries revived their use as a matter of prestige, this use has now also ended. However, one informant reported that hunters are currently installing water troughs near a spring for wildlife watering (la Bisbal de Falset). In mountain areas where livestock propagation continued through the 20th century, springs were the only places where water was available for livestock; mainly for goats and sheep. These springs were often developed by installing *bassis*, troughs made up by a set of hollowed logs arranged in a line to facilitate animal watering. These structures can still be found in many springs of the massif (Figure 12). This use has disappeared along with the herds, but it has been possible to verify that the springs supplied with *bassis* are places still frequented by a great diversity of wildlife.

Figure 12. Troughs constructed of hollowed logs (*bassis*) for animal watering in Manyano spring (**left**) and Clot del Cirer spring (**right**). Even though the last herds of goats grazing on the mountain disappeared years ago, these two structures have been recently restored by the Natural Park. Photo credit: R. Pascual.

In villages located on the south face of Montsant where vineyards are widespread, the informants reported the use of water from the springs for phytosanitary treatments, mainly to make the so-called *caldo Bordelès* (Bordeaux mixture), a solution of copper sulphate and lime used to treat fungus, particularly in vineyards.

Although not a widespread practice in Montsant, some springs were used for washing laundry, an important social tradition. All villages in the rural areas had public wash places where women went to wash laundry, a routine but cumbersome task. In some cases, these wash places were located next to the springs, consisting of water-filled basins and a scrubbing deck. For example, wash basins are connected to Sant Miquel and de Baix springs, the latter restored at the end of the 20th century (Cabassers), as well as Font Vella Spring, also recently restored (La Figuera, Figure 13). Palomar [109] collected the references of the informants regarding Poble spring (Albarca), where the wash basin consisted of a natural depression in the rock with slate slabs installed for scrubbing clothes. When this spring dried up, laundry washing had to be performed at Teix Spring, 20 min from the village. The wash areas were, of course, also places of socialization, where in addition to washing, women talked with their neighbours, recited folk tales, and sang ballads [109].

Figure 13. Wash place next to the Font Vella spring (la Figuera). This structure was restored in recent times, with repairs to the masonry wash basins and stone scrubbing decks. Photo credit: R. Pascual.

Montsant is a land of hermitages where gatherings, celebrations, and pilgrimages are held on designated dates (Table 2). Some of these hermitages are located next to natural springs which become a main element of the celebration (Cabassers, la Bisbal de Falset, Margalef).

Table 2. Celebratory events in some springs in the Montsant massif.

Spring	Date	Calendar of Saints	Village that Organizes the Event
Santa Llúcia	2nd Sunday in August *	---	la Bisbal de Falset
La Foia	25 April	Sant Marc	Cabassers
	5 August	Mare de Déu de les Neus	Cabassers
Sant Salvador	25 April	Sant Marc	Margalef
	6 August	Sant Salvador	Margalef
	16 August	Sant Roc	la Bisbal de Falset

* Santa Llúcia (Saint Lucy) falls on 15 December, a date when it is usually very cold, and for this reason the celebration takes place in August.

Other occasional uses of springs mentioned by informants were related to construction and wildfire facilities. Spring water has been used to make mortar for covering the walls of the typical small stone shelters of la Vilella Baixa, and for house repairs in Albarca [109]. In addition, some springs are diverted to supply pools throughout the area used to extinguish wildfires (la Morera de Montsant).

Long-term Discharge Variability: An issue of great local and global interest is assessing trends in spring discharge over long time periods, in this case over the course of the informants' lives. Most informants declared themselves unable to answer this question. Among those who did give an answer, there were contrasting opinions: some believed that overall spring discharge had decreased (La Morera de Montsant and la Vilella Baixa), but other informants did not see appreciable changes (Ulldemolins, la Figuera, and Torroja del Priorat). In one peculiar case, decreased spring discharge was attributed to landscaping an adjacent mass grave site dating to the Spanish Civil War with cypress and European nettle tree (Escaladei). In other cases, decreased discharge was attributed to a lack of maintenance (Cabassers, Margalef, and la Morera de Montsant). Most springs in the study area have an outflow forced by drilling into the terrain until reaching the water-bearing vein. Such systems tend to collapse over time due to sediment clogging, and therefore must be periodically cleared.

Causes attributed to the loss or disappearance of springs: A continual loss of springs was reported by all informants. All had heard of springs they never saw and knew of springs that are now missing or engulfed by vegetation. Although it is known that springs can collapse in short periods if not regularly cleared, the outflow may be suddenly choked for other reasons (Figure 14).

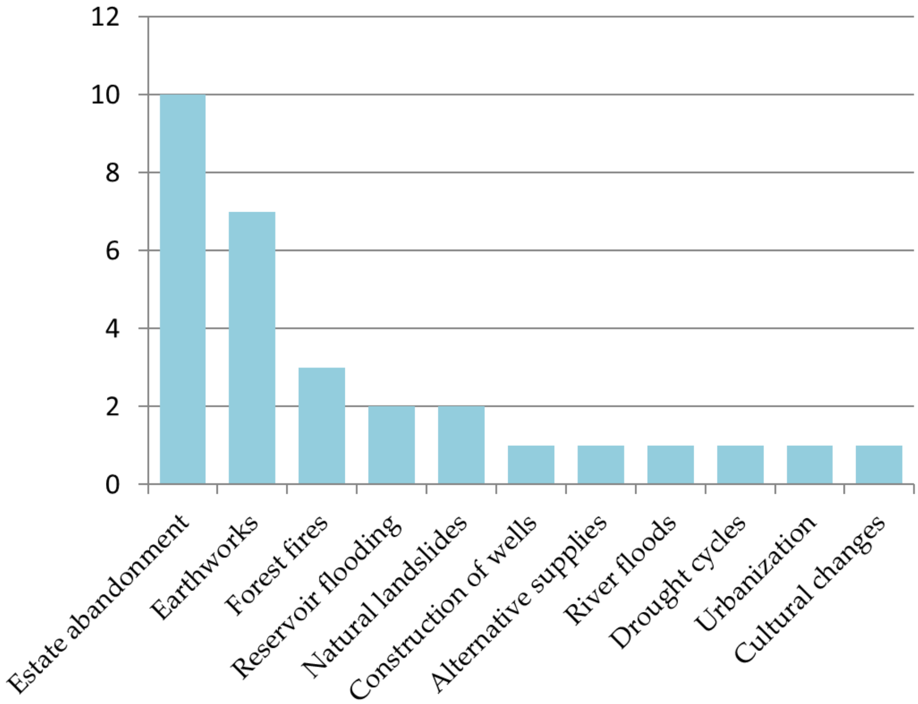


Figure 14. Number of villages where the key informants have reported the listed causes of spring loss or disappearance (n = 13); several were reported for some villages.

Most of the informants mentioned the abandonment of crop agriculture, a trend throughout the 20th century which continues today, as the main cause of spring loss (Poboleda, la Bisbal de Falset, Cabassers, Escaladei, Margalef, la Morera de Montsant, Ulldemolins, la Figuera, la Vilella Baixa, and Torroja del Priorat). As highlighted above, many small springs were associated with crop plots and were used almost exclusively by the owners. This type of spring is doomed to disappear in a few years once cultivation is abandoned.

Another cause to which many informants attribute the loss of some springs are earthworks such as terraces, which facilitate agriculture (Escaladei, la Bisbal de Falset, Cabassers, and Torroja del Priorat), or the construction of roads (la Bisbal de Falset and la Vilella Baixa) or forest paths (la Morera de Montsant, and Ulldemolins), which sometimes involves drying out springs in the nearby area. Many of the informants explain this phenomenon by associating these works with a reconfiguration of the channels through which the underground water circulates.

A similar argument is made regarding the effects of wildfires (Escaladei, la Vilella Alta, and Figuera). In this case, the informants believe that the channels left by the roots of burned trees which end up rotten lead to changes in groundwater circulation, which would explain why outflow ceases. Natural landslides have also been associated with the sudden drying of springs, for reasons similar to those described above for anthropogenic earthworks. Springs which have been lost after becoming submerged under the water table of reservoirs were reported by two informants (Margalef and Cornudella de Montsant).

The remaining potential causes listed in Figure 14 were indicated by only one informant. The construction and exploitation of wells was described for Cornudella de Montsant. The development of alternative water supplies, such as modern irrigation networks, has also favoured the abandonment and loss of some springs (la Bisbal de Falset). The cultural change of replacing pack animals with motor-driven vehicles might also be a cause of spring loss since farmers are less likely to follow the traditional custom of having lunch at the plot near a supply of fresh water (Torroja del Priorat). The informant from Vilella Baixa provides two additional empirically demonstrated causes: river flooding and urbanization. The heavy flood which occurred in October 1994 would have caused the disappearance of two springs that drained near the Montsant riverbed. During the paving of village streets, two springs located in the urban area were connected to the sewer system that was installed simultaneously. Paradoxically, two urban fountains fed by the drinking water network were then built in both locations. Finally, it has also been argued that periodic cycles of severe drought might drive the disappearance of springs, since when known springs dry up, people try to find new veins in the vicinity. If this search succeeds, the original springs tend to become lost (Ulldemolins).

Some lost or abandoned springs were recovered in recent times, with varying degrees of success. In some cases, recovery or restoration was carried out by the city council because nearby springs well-known to the residents are involved (Poboleda), or because these springs are located close to roads (la Morera de Montsant). In others, the initiative arises from the management of the natural park, which has recovered several mountain springs by, e.g., replacing traditional wooden troughs damaged by the passage of time (la Morera de Montsant, Figure 12).

Does it make sense to recover or rehabilitate lost springs? Among the informants there is the general consensus that it does not make sense to recover abandoned or lost springs if there is no clear use planned for them (Cabassers, Margalef, Ulldemolins, la Figuera, and la Vilella Baixa) or if they do not include dry stone constructions or other heritage elements (Torroja del Priorat). Accordingly, it may make sense to recover some springs close to the villages (Poboleda, la Bisbal de Falset, and la Vilella Baixa), or linked to hiking or other types of outdoor activities (Poboleda, Margalef, and Ulldemolins).

Human Health and Balneotherapy: The informants were asked about public health incidents related to these springs, as well as about the therapeutic properties of their water. None of the informants remembered any incident of poisoning or epidemic due to the consumption of water from the springs. On the other hand, some informants did report beliefs about the healing properties of the water from the springs. One of the springs had been used in a case of a child patient with tuberculous spondylodiscitis, known as Pott's disease (Escaladei). In Ulldemolins, the water from the Mina spring was consumed for diuretic purposes due to its low salt content. In la Vilella Baixa, the water from a ferruginous spring was given to people with whooping cough (pertussis). In Albarca, it is told that children with whooping cough were made to drink water from nine different local springs [109].

Legends, Mythology and Folklore: The Font Vella spring (also known as Silvestre spring) near Ulldemolins holds the oldest reference in the village and most likely in the whole study area, with its existence documented as early as 1286 [111]. A legend tells that the image of Virgin Loreto was found there, motivating the construction of the Loreto hermitage at the entrance to the village.

In the case of the Font Nova de Cornudella de Montsant, it was thought that the spring water came from the Pyrenees more than 100 km to the north, since its flow increased after periods of elevated temperatures, corresponding to accelerated snowmelt.

As in many other aspects of the rural world, there is a documented belief in the influence of the lunar cycle, in the sense that if the springs were cleared during the Waning Crescent Moon, the flow increased, while if it was done at the New Moon there was a risk of decreasing the discharge or even drying it out [109].

A beautiful legend explains the appearance of the five most abundant springs in Albarca, all of them located near the hamlet of Mas d'en Lluc. According to this oral tradition, a hermit living on the top of Monsant long ago announced the birth of Jesus Christ to the people dwelling in Albarca, disappearing soon after. About 30 years later, he returned to the village and converted its residents to Christianity. Shortly afterwards, for three consecutive nights, a huge image of Jesus on the cross made out of moonlight appeared before the village, with its hands reaching the top of the cliff of La Gritella and its feet touching the ravine of Argentera. Rays of light emitted from the wounds on his hands and feet, as well as from the gash on his side. The hermit recounted to the neighbours the passion and death of Jesus Christ, which he had known through revelation. Once Christ was resurrected, the rays of light which had spilled from the wounds became the springs of Grau, Puntal, Freda, Mas de l'Oliver and Canals. In this way God provided the inhabitants of Albarca with abundant water in recognition of their conversion [109].

Aside from these beliefs and legends, most local spring folklore was linked to washing laundry. Wash places were the main points of female socialization, as described above. Several tales and ballads were recited or sung in these places. The folk tale *El festeig a la font* ("the courtship at the spring") tells a story of a spring as the place where boys seduce girls. The ballads of *Caterina d'Alió* and *Les tres ninetes* ("the three little dolls") revolve around the same topic [109].

Other Aspects of Interest: Another interesting topic is the taste of spring water. The informants speak about some springs with strong-tasting water and others with water described as *molla* (feeble or weak, i.e., tasteless), such as that of Poboleda, Cabassers, la Morera de Montsant, Cornudella de Montsant, la Figuera, la Vilella Baixa, Torroja del Priorat, and Albarca. While the former are considered good for drinking, the latter are often dedicated to other uses (particularly irrigation). In one case, the owners of a spring occasionally added some lime to the next storage basin to improve the flavour of the water (la Vilella Alta), demonstrating that the taste of the water was already related to its salt content. Some informants emphasized the iron flavour of the water from some specific springs (Vilella Alta, Vilella Baixa, Torroja del Priorat) or the fact that it leaves a thin coating of iron oxide on the surfaces it soaks (Cornudella de Montsant).

On a different historical note, some people who had inhabited Albarca remembered a curious custom well-documented by oral transmission. Towards the end of the rule of the Escaladei Charterhouse over most of the lands of Montsant, the farmers who cultivated Carthusian properties were obliged to pay a unique, symbolic tax consisting of a bottle of water from a spring located around the terrain they cultivated, which was to be brought to the Carthusian prior once a year. In exchange, the farmers were invited to eat a meal at the Charterhouse [109]. This unequal trade exemplifies the enormous symbolic importance related to springs.

Discussion and Conclusions

This case study provides an in-depth example of the close relationship between rural societies and Mediterranean spring ecosystems. It is worth considering that the age of the informants places most of their statements and memories within the first half of the 20th century. In fact, these are the last generations that lived in a world characterized by a huge gap between urban, industrialized, and modern society and the rural, traditional world with its close relationship to nature. Throughout the last century, these differences have faded and become very small in our current society with its technology and relational networks. The study area is a Mediterranean mountainous area in the hinterland of the coastal plain towns which did not experience modernization until the 1970s. Therefore, information from the memory of the 13 people interviewed (plus that of the 11 witnesses collected in [109]) constitute a document of immense value given that this generation is disappearing.

The informants tell us of a time when springs were much more abundant and had a much greater importance than at present, pervading most of the vital aspects of society. Certainly, water has always been an essential element for the establishment of life, especially in Mediterranean areas where it is scarce when it is most needed, during the summer season. In the study area, many river reaches dry up or dramatically decrease their discharge during summer, so that the springs became, for most of the population, the only water source for drinking, producing food (enabling both the irrigation of sustenance vegetable gardens and watering livestock), for fuelling their “machines” (watering pack animals), for washing laundry, and for personal hygiene. It is therefore not surprising that springs were also the subject of festive events and celebrations.

The implementation of urban supply systems and the construction of reservoirs and irrigation networks starting in the second half of the 20th century, combined with a decline in agriculture and the progressive abandonment of many cultivated areas, precipitates the disappearance of many local spring ecosystems. Present-day interest in springs is limited to use by hikers and other practitioners of outdoor activities, citizens concerned with preserving their cultural value, and small academic circles that appreciate them as biodiversity hotspots.

This fact invites serious reflection. Springs have been, in the Mediterranean area, essential elements for permanent settlements. The necessity of permanent water fuelled the search for shallow veins and methods to concentrate groundwater emergence and flow. In this way, humans inadvertently multiplied a network of water points comprising a meta-ecosystem which harbours remarkable biological richness and diversity [60]. Paradoxically, with the abandonment of cultivated land and re-naturalization of the environment, the superficial expression of the water from the springs is being lost and, with it, knowledge, traditions, and biodiversity. Urgent and determined action is therefore needed to preserve what has come to us: the remains of a treasure that perfectly represents the synergy of natural and cultural heritage, and an ecosystem where the line separating the two becomes blurred, and the concepts of artificiality and naturalness become liquid.

3.3.3. Mediterranean Basin: Spain—Mallorca Island

Introduction

The island of Mallorca is an archetype of Mediterranean life in relation to the environment and history. Its small area precludes the existence of surface streams suitable to guarantee an uninterrupted water supply. In contrast, the presence of an important limestone massif (the Tramuntana mountain range) favours abundant orographic rainfall in winter season on the north of the island [112] and harbours a karst system which stores excess precipitation in large underground water bodies [113]. Groundwater is the only water resource in Mallorca. It is not strange, therefore, that springs have played a crucial role in societal development on the island, probably since prehistoric times.

In this case study, we discuss the Spanish Mallorca Island springs database (MIS db; www.fontsdetramuntana.com, accessed on 28 November 2023), the result of an intensive cultural inventory of about 1700 Mallorcan springs. Although this was not its initial objective, this project became a thorough inventory of the springs of the island. The website was created by Andreu Morell at the beginning of 2011, and the team was soon completed with Mario Fontán and Pedro Fidel Castro. The conceptual scope of the project involved defining a spring as a place where groundwater flows naturally or through an excavation to the surface, aided only by gravity and not by any other energy source. An additional criterion was the intention to make some specific use of the water (e.g., Figure 15). Over a span of 11 years (2011–2021), information on more than 1500 springs located throughout the island was added to the website.

Figure 15. *Fonts des Tions*, spring-flow tunnel located in Artà mountains, east Mallorca. Photo credit: P.F. Castro**.**

Methods

The research methods were described in detail in [114]. The many sources of data included general local literature, a specialized bibliography on hiking, hydrological literature, popular architecture, modern and older cartography, aerial photography, historical archives and, of particular importance, oral information. Concerning the latter, Castro [115] noted that only approximately half of the springs in two different study zones appeared on any known map, and 18% of all of the located springs had never been previously documented in any known text or map.

Field work was focused on describing structures and uses of the water. It was carried out with the specific objective of looking for springs from which some data on the approximate location may have been previously noted. The information published in the database consists of the location, including the coordinates and name(s) of the place where the spring is located; the type of property; the main use; the typology of the main structures; and a description of the most important subjects related to the spring. Importance was always given to the name of the spring (toponymy), and an effort was made to identify each one with the name by which it had been known historically. Field descriptions were always accompanied by photographs and a sketch of the spring, including the associated vernacular stone structures that protect most of them, and explanations about the types and functions of these structures. Spring diagrams may include front, side, and plan scale representations of the associated structures and their surroundings.

Results

Mapping: There are currently 1671 Mallorcan springs published in the database, of which approximately 1400 are located in the Tramuntana Mountain range along the north-western coast of the island (Figure 16). It is estimated that about 95% of all springs in Mallorca have been registered in the database, but additional springs may continue to be discovered, including some with extensive hydraulic systems. The last major finding, not yet published on the web, was in April 2023: es Fontanals, a small spring with a channel >2200 m long that traditionally provided water for an oil press in the mountains of Artà, east of Mallorca (Figure 17).

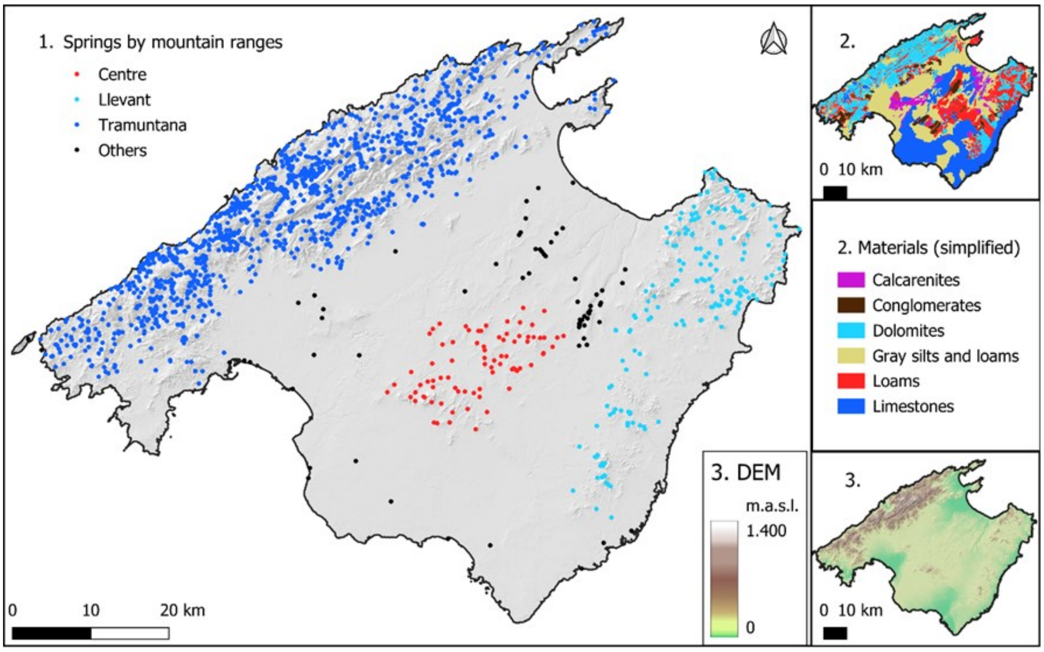


Figure 16. Location of the springs in Mallorca.

Figure 17. *Es Fontanals* spring (**Left**) and its channel, now in ruins (**Right**). Photo credit: P.F. Castro. Ortophoto (2021 flight) from IDEIB (Infraestructura de Dades Espacials de les Illes Balears).

Distribution: The distribution of the springs in Mallorca is clearly heterogeneous (Figure 16). Most of the springs are located along the Tramuntana Mountain Range, but there are two other groupings located in central Mallorca (81 springs) and the Llevant Mountain Range (212 springs). In the Tramuntana Range, dolomites predominate. This lithology favours the infiltration of rainwater which finds its way to the surface where the dolomites meet impermeable materials, predominantly clays and loams.

The Tramuntana Range has a surface area of about 1050 km^2, with a resulting density of 1.33 springs/km^2. Although the range reaches 1445 m a.s.l at Puig Major, 82.5% of the springs are located below 500 m a.s.l. and only six occur above 1000 m a.s.l.

Typologies: The Mallorcan springs were classified by categorizing the manmade structures that allow groundwater to flow towards the surface. This classification led to the identification of four groups of springs: dripping springs, raw springs, *qanats*, and spring-flow tunnels (Figure 18). The main categories into which the studied sources are grouped are listed here, from least to most complex:

- Dripping springs *(Degotís*): Inside some caves and at the base of cliffs, in the places furthest from other water sources, there are some dripping springs that usually consist of ceramic cups or jugs, or small excavated basins in which the water that falls from the ceiling or overhang is collected. Some of these were located on cliffs near the sea, where men could leave jugs to fill while they fish (Figure 18G).
- Raw springs *(Fonts* or *brolls*): These are usually the simplest springs that flow from the ground (Figure 18D), with little modification beyond perhaps the excavation of a pool. *Fonts (*described below) have a greater degree of development in the dry-stone structures surrounding them (Figure 18A). The degree of development in the structures is not related to the extent or quality of water management structures. Also, the exact point at which a spring becomes a mine cannot easily be determined, since they are sometimes covered with shallow dry-stone structures (Figure 18B).
- *Qanats:* The *qanats* exist with the same variations seen in the spring-flow tunnels category, but always have at least one vertical shaft (Figure 18E,F,J). Also, there may be a *noria* on top of the first vertical shaft, leading to the irrigation of a bigger area situated at another level.
- Spring-flow tunnels *(Fonts de mina*): These are tunnels without any vertical shaft leading to the surface. Mines may not have internal structure (Figure 18C), but may have small ponds at their entrance (Figure 18B) or wells in their depths. Some mines lying slightly below the water table also have been used as cisterns (Figure 18H). Also, mines dug only at the spring outlet can transform into wells, which may be accessible by underground staircases (Figure 18I).

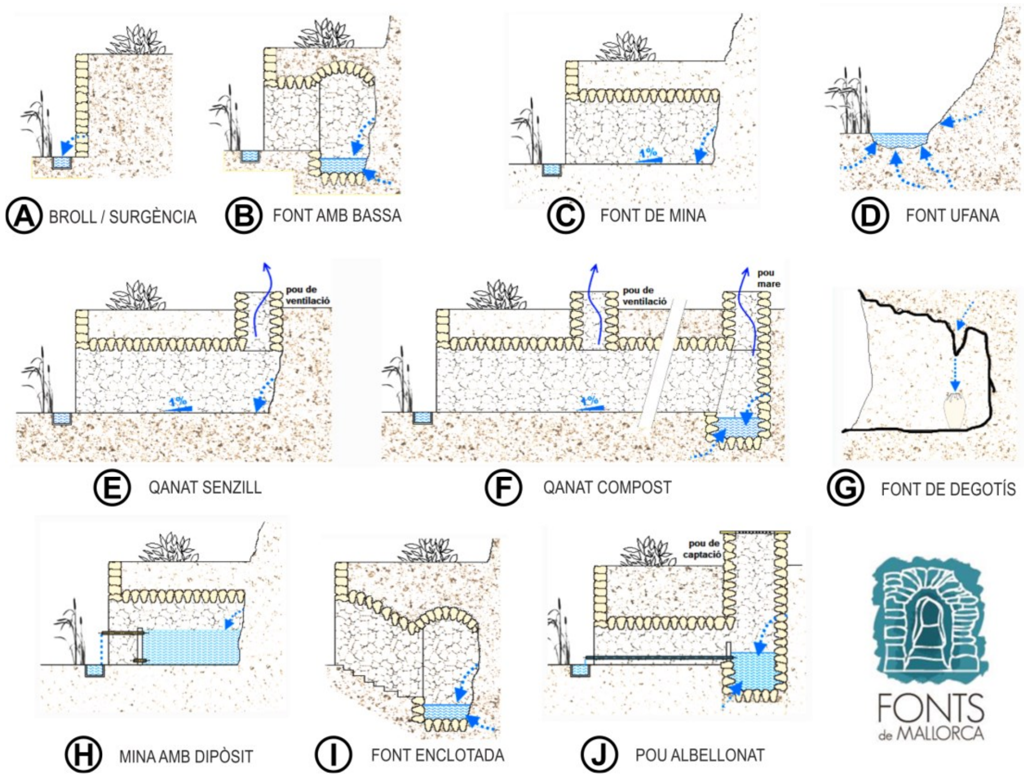


Figure 18. Classification of the springs in Mallorca; modified from sites.google.com/view/fontsdetramuntana (accessed on 2 December 2023). See main text for explanation of typologies.

Our definitions of the concepts of *font de mina* (spring-flow tunnel) and *qanat* differ from those of other authors. For example, Ron [116] defined *qanats* as any excavated water tunnel. Morell and Fontán [117] indicate that there are 880 springs with a tunnel structure in the Tramuntana Range (62% of all the springs), of which 169 are *qanats* and 711 are spring-flow tunnels. Approximately 90% of these structures were constructed using the dry-stone building method, without any mortar binding. This technique allows the water to flow through the walls and usually prevents the structure's collapse. Only some structures repaired during the 20th century have mortar on their walls. On rare occasions—usually in solid bedrock—the excavated tunnel has no protective wall.

The spring-flow tunnels are usually no more than 15 m long, straight, and perpendicular to the highest slope or with a slight angle. Also, the length of the mine is directly related to the average slope of the surrounding terrain. In flat areas the tunnels are much longer, and vertical shafts are needed to provide air or access to the tunnel for repairs. Thus, *qanats* are usually much longer than spring-flow tunnels, with some in excess of 200 m long, with >10 vertical shafts (Figure 19).

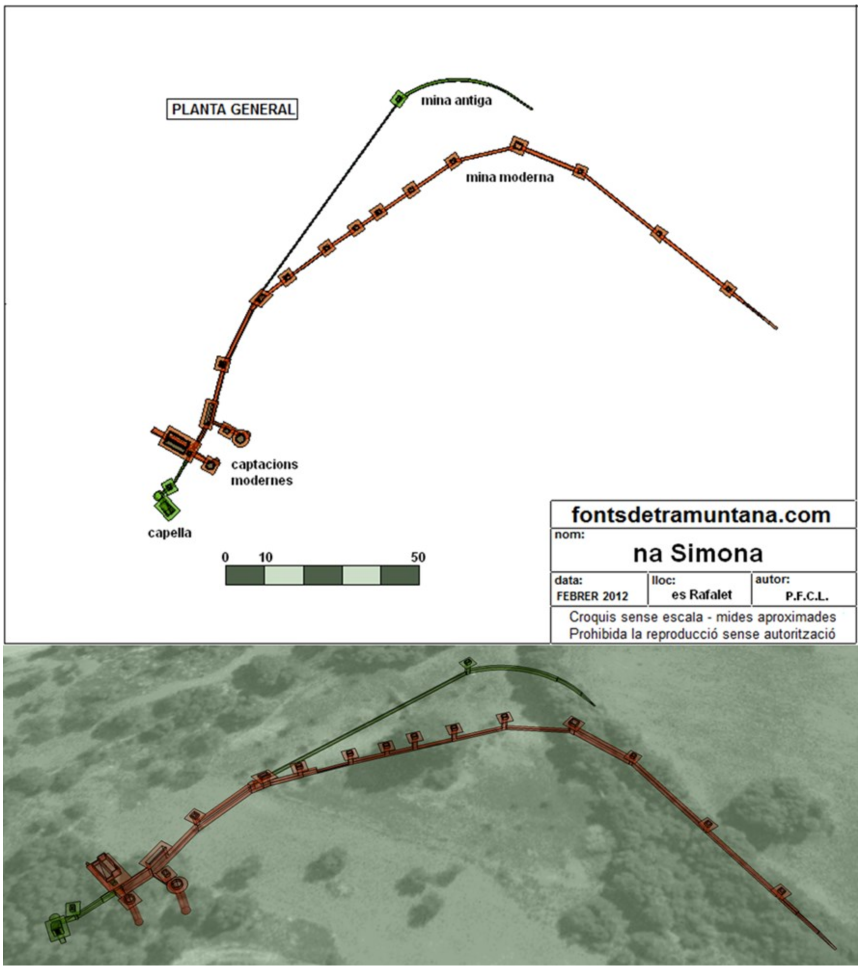


Figure 19. Na Simona or Font des Rafalet, a *qanat* located in Son Servera, east Mallorca, has two flow tunnels. The remains of the older tunnel (green) measures 93 m, with two vertical shafts; the new tunnel (red; structures built or modified during the 1950s) measures 182 m and has fourteen vertical shafts. Ortophoto (2012 flight) from IDEIB (Infraestructura de Dades Espacials de les Illes Balears).

Historical Evolution of Spring Structures

The location of Mallorcan springs is related to lithological and geological settings. In many cases it seems that without the manmade structures, discharge to the surface would be less than it had been historically. Although the springs of Mallorca are traditionally associated with the era of Islamic domination (902–1229 CE), there has been discussion on the possible Roman origin of some extant flow tunnels. Aguiló [118] proposed a Latin origin of the toponym Xorrigo, for a spring-flow tunnel, the name derived from *sub riguus* (standing for underground flow). In another case, the Font de Crestatx contains archaeological remains that date these structures to the first centuries BCE.

Many springs appear in documentation from the 13th and 14th centuries (the first centuries after the Christian conquest) and have been subject to hydraulic archaeology studies by Barceló and Kirchner [119], among others. However, the springs recorded in the database are far more numerous than those cited in hydraulic archaeology articles. We found no relevant differences between springs clearly established during Islamic rule and others with well-documented construction during the following centuries. It is remarkable that the construction of a well or a spring-flow tunnel near a previously existing spring created many court cases related to the theft of water (e.g., the case of the Font d'en Baster, which lasted for centuries [119]) (Figure 20). Also, oral communications and local literature reveal that some Mallorcan spring-flow tunnels were excavated as late as the 1930s.

Figure 20. Font d'en Baster. Reproduced from sites.google.com/view/fontsdetramuntana (accessed on 6 December 2023). Photo credit: Mario Fontán.

Many springs have remained perennial during the past centuries. Re-excavations and the deepening of springs that had dried up during droughts or because of overexploitation were documented, but these were never abandoned or destroyed, simply retained for future recovery of flow. One well-documented example is the Font de Santa Margalida in Felanitx, Mallorca, an Islamic *qanat*, which dried up during the severe drought of 1490 and was subsequently deepened [120]. Its flow returned on the day of Santa Margalida (20 July); she thereafter became a patron saint of the city. Only with the introduction of water-pump mills and extraction pumps in the late 19th century has the traditional use of spring-tunnels and *qanats* ended.

Uses and Structures: Among the most common uses of spring water in Mallorca is agriculture. In some cases, the water was used for watering animals, but it also irrigated fodder plots. Human need was also a common use of spring water, if it maintained a flow of sufficient quantity and regularity and was protected from livestock contamination.

Spring water also had different industrial uses, mainly related to hydraulic engineering in mills with different functions, such as grinding cereals and legumes, fulling, or making paper pulp. However, it also had direct uses, such as improving oil production in the oil mill or simply watering threshing floors to flatten and minimize grain loss during threshing. Also, almost every town in Mallorca had a public washing place near a spring.

Uses that created the most complex and larger structures were related to irrigation. On every property, springs with regular flow, no matter if meager, were used to grow crops, mainly vegetables. Although this has not been quantified, a study in eastern Mallorca in the late 19th century reported that 45 springs were used for the irrigation of 49.5 ha [114]. That study also indicates that the five springs with greatest discharge were used for the irrigation of 33.1 ha, whereas each of the remaining springs irrigated an average area of only 0.4 ha.

The same pattern was observed in the Tramuntana Mountains, where irrigated plots were characterized by heritage materials, such as stepped-terrain *marjades* (terraces delimited by dry-stone walls) for conditioning steep terrain that extended across 194 km^2, as well as canals, wash basins, troughs, washing places, and cisterns (Figure 21). Springs with limited discharge are often associated with troughs for animal watering. There were some reports of *obis* (troughs made with hollow logs) at some springs, but none were observed by the authors.

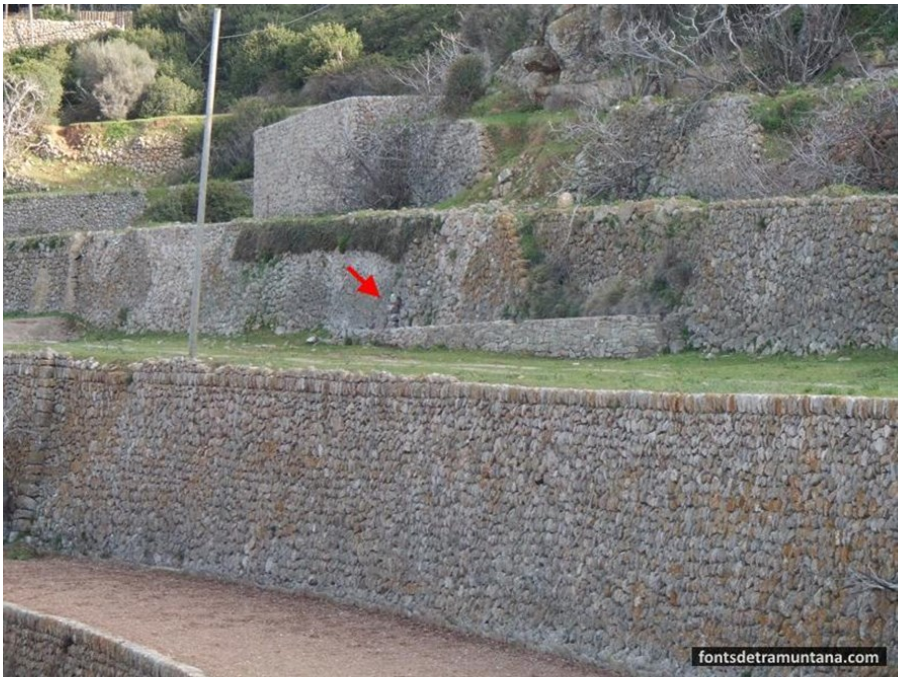


Figure 21. Font de sa Basseta, a spring-flow tunnel located in Banyalbufar in a stepped terrain area. The red arrow indicates its outflow point. Reproduced from sites.google.com/view/fontsdetramuntana (accessed on 6 December 2023). Photo credit: Andreu Morell.

Resting and recreational uses were found in springs located within properties that could afford them. In some, artificial caves or grottoes were built at the entrance to the mine, and stone tables and seats were installed to take advantage of its refreshing atmosphere (Figure 22).

Figure 22. Font de sa Gruta. Reproduced from sites.google.com/view/fontsdetramuntana (accessed on 6 December 2023). Photo credit: Mario Fontán.

Present Status and Future of Mallorcan Springs

Many Mallorcan springs have become, at best, places of leisure and tranquillity, with uses completely different from those that characterized them in the past. Perhaps these are the springs with the best prospects of conservation, since they receive the most attention from the owners.

In most cases, springs located in more hidden places or far from settlements are completely abandoned. The abandoned springs continue to flow for some years until a lack of maintenance causes the accumulation of sediments and the creation of limestone deposits that finally cover the structures and block the outflow. Therefore, the water itself foments the collapse of the spring and condemns it to disappear over time.

The springs located closer to inhabited areas have been drying up progressively during the last century due to the introduction of mechanical means for water extraction which led to a drop in the water table. In addition, the growth of tourism in Mallorca has resulted in the long-term abandonment of farmland throughout the island. Also, in many of the springs which still flow, the water has been channelled with piping, leading to the disappearance of associated ecosystems.

The Tramuntana Mountains area in Mallorca has the best chance of conserving at least part of the material heritage associated with springs, since crop irrigation is more difficult and groundwater depletion has been much less drastic than elsewhere. The declaration of the Tramuntana Range as a World Heritage Site in 2011 was based on its cultural history which extends back millennia, reflected to a large extent by the dry-stone structures linked to the management of springs. The Tramuntana Range has also been declared a Natural Site and included in the Natura 2000 Network due to its ecological value. The balance between protecting natural and cultural values requires careful planning because an overprotection of the former could lead to the forced abandonment of traditional use. If the use of springs is not allowed, or if traditional methods are discouraged, hundreds of spring ecosystems will degrade due to the clogging of mines, filling of ponds, and destruction of the historic structures that allow the water to reach the surface.

By contrast, for springs in the east and centre of Mallorca, the entry into the 21st Century does not offer positive perspectives for improving spring management. Many of them are already dry or abandoned, if not destroyed by draining. This also applies to the network of irrigation canals that had been used for centuries.

Discussion

Spontaneous outflows of groundwater are rather scarce in Mallorca, so when techniques for digging and building mines and *qanats* were developed, especially during Islamic rule [119], agricultural exploitation could expand to new areas. This activity remained mostly unchanged until the 20th century, resulting in a strong increase in the density of springs in the territory, particularly in the Tramuntana range. In this massif of just over 1000 km^2, around 1400 springs have been identified and characterized, an estimated 95% of potentially extant springs. It is important to mention that almost 900 of these springs are associated with underground galleries (mines and *qanats*). without which they would not flow. As for the rest, many of the springs also flow through much more superficial excavations or drillings (such as a simple centimetre-sized hole. In a recent study in 10 springs of the Tramuntana range, biological richness was much higher in springs compared to the immediate environment [52]. Thanks to the environmental stability they provide, spring habitats are also a refuge for endemic and threatened species [121].

From the second half of the 20th century, Mallorca has undergone accelerated socio-economic change, leading to a strong predominance of the tertiary sector and recession of agriculture and livestock production to residual levels, leading to the loss of associated springs. In many of the springs that are still used, traditional elements are increasingly replaced with modern solutions that minimize water loss (e.g., open basins are replaced by closed cisterns, and canals by pipes), removing the surface expression of water. In addition to the degradation of traditional stone structures due to a lack of maintenance, the microhabitats sustaining spring biological communities are also eliminated. Many springs in the centre and south of Mallorca will disappear in the near future, while springs in the Tramuntana Range are more likely to persist. It is essential to move towards active preservation of this heritage, which represents a unique and unrepeatable lesson on the relationship between humans and nature.

A symbolic image of the ancient relationship between humans and water can be taken from the science fiction film 2001: A Space Odyssey. At the beginning of the film, a group of hominids, led by a leader, barely survive in an arid and hostile environment. One day, the group heads into the territory of another group to regain the previously lost waterhole. Water has long been a jealously guarded object of contention since the earliest origins of humans [59], and unfortunately is still at the heart of arguments across the social scale (e.g., wars for the "blue gold").

3.3.4. Mediterranean Basin: North Africa

Introduction

The springs in the Arab Maghreb of Northwest Africa have not only quenched the physical thirst of the population but have also nourished their spiritual and cultural identity. The enduring connection between springs and culture is a testament to the resilience of ancient practices in the face of a changing world. In arid areas, access to water can become a source of conflict which is exacerbated by the effects of climate change [122,123].

Cultural and Religious Relationships

The springs in this region are closely interwoven with the cultural fabric of the Maghreb and celebrated through various ceremonies and festivals. The landscape is adorned with springs bearing names such as Aïn Makhlouf (Makhlouf's Spring), Aïn Beïda (White Spring), Aïn Berda (Cold Spring), and Tala Rana (Spring of Frogs), each with a unique history and meaning. Towns and villages bear these Arabic or Tamazigh names with pride and are a living testimony to the vital role of springs in the region. Thermal springs in particular are sanctuaries of relaxation and healing throughout the Maghreb.

The connection between springs and culture is very close in the spiritual realm of the Maghreb. In Islam, a cornerstone of Maghrebian identity, water symbolizes purity, leading many devout people or saints to find eternal rest near these life-giving or "holy" springs, each with its own history. Although the tradition of dedicating festivals to revered saints and to the springs themselves has been criticized by Islamic purists, it dates back to the arrival of Islam in the region. Springs such as Kattara, the "oozing or leaking spring," and Aïn Bent Soltane, the "spring of the sultan's daughter", near Annaba (Algeria) embody this enduring spiritual connection.

History

Ancient Roman heritage in the Maghreb includes an extensive network of aqueducts, baths, and fountains that harness the power of the springs [124]. The city of Hippone (now Annaba), for example, was supplied by Roman aqueducts that brought spring water from Mount Edough, and the fountains were decorated with large Gorgon masks made of white marble. The Zaghouan aqueduct and the Aghlabid cisterns in Kairouan, Tunisia, also show the Roman and Islamic influences on the region's water infrastructure. Cisterns, which have been used throughout the Mediterranean for thousands of years, have eased seasonal fluctuations in the water supply [125].

Socioeconomic Aspects

The art of *foggaras* is an essential part of the cultural and economic heritage of the Maghreb, especially in the arid regions of the Sahara. These underground aqueducts, which form an elaborate system of tunnels and canals, have significantly influenced the region's culture and way of life. Beyond their practical use, the *foggaras* symbolize unity and collective effort. Their construction and maintenance promote the values of cooperation, shared responsibility, and mutual support within the community. In recognition of the importance of *foggaras*, UNESCO declared the knowledge and skills of their water measurers as Intangible Cultural Heritage in 2018.

3.3.5. Mediterranean Basin: Italy

Introduction

Many sites in Italy testify to the ancient connection between people and springs. One of the oldest testimonials is the prehistoric site of Poggetti Vecchi (Tuscany). A geological peculiarity of this site is the resurgence of thermal springs along a fault contact between limestone and clay deposits. According to radiometric dating, it was frequented by an ancient Neanderthal population around 171,000 years ago, probably for the plant and animal resources that the thermal area offered in the period of climatic shifts during the late Middle Pleistocene [126]. Poggio Vecchi is one of only a few examples among European archaeo-palaeontological sites revealing the transition from the Middle to the Upper Pleistocene and offering insight into the behaviour of ancient Neanderthals. Sculpted boxwood sticks from Poggetti Vecchi represent an exceptional find, showing the earliest evidence of fire being used as a tool for woodworking [126,127].

Archaeology

This bond continues in the territory of San Casciano dei Bagni, which represents one of the richest geothermal regions in Italy, with a long tradition of thermal spring use. Groundwater temperatures range from cold water with low concentrations of mineralized calcium-bicarbonate to warm (>40 °C), highly mineralized waters enriched with calcium and sulphate. Studies indicate that the recharge area is in the Cetona basin and circulation happens in a highly fractured aquifer formed in Mesozoic limestone, with an underlying aquitard of the Burano Anhydrite Formation [128]. Archaeological investigations in sediments associated with geothermal springs recently produced treasure dating back to Etruscan times, which included coins, votive offerings and inscriptions, and 24 Etruscan-Roman bronze statues depicting gods, matrons, children, and emperors. Some of these artifacts included depictions of the god Apollo and the goddess of health, Hygieia. These findings date from the 2nd to 1st century BCE and suggest that the Etruscans considered water to have sacred value and that they appreciated its beneficial effects. This is the largest find of statues from the Etruscan-Roman period to date (https://cultura.gov.it/bronziscasciano, accessed on 10 May 2024).

During the Roman era, hydraulic science reached its fullest expression in the construction of numerous imposing aqueducts, up to tens of kilometres long, which transported water from distant springs to urban centres. The selection of water for public distribution considered the origin of the springs, the transparency, taste, and temperature of the water, a permanent flow discharge, and, most importantly, an adequate elevational gradient to get the water to the urban area. Water treatment was practically non-existent, limited to simple decantation in limestone basins positioned along the conduit.

The remains of Roman aqueducts can still be seen in several Italian regions. In the imperial city of Rome, freshwater was provided by 11 aqueducts, altogether about 500 km long. These ensured that the city had enough water to satisfy the needs of a population of about one million inhabitants, including supplying public fountains and thermal baths. Of these 11 aqueducts, the Roman aqueduct of the Acqua Vergine (*Aqua Virgo*), inaugurated on 9 June 19 B.C., is the only one that has remained in uninterrupted function to this day, supplying parks, gardens, flowerbeds, and fountains in the centre of Rome. The latter include the Trevi Fountain (18th century, Figure 23A), the Barcaccia in Piazza di Spagna (17th century, Figure 23B), and the Fountain of the Quattro Fiumi in Piazza Navona (17th century). In modern times, the Trevi Fountain has been immortalized in cinematic masterpieces. In Federico Fellini's film "La Dolce Vita", an irresistible Anita Ekberg whispers, "Marcello, come here" to catch the attention of Marcello Mastroianni, inviting him to bathe with her in the clear waters of the fountain before baptizing him in a subtle movement. This iconic scene is etched into the collective memory of Romans and non-Romans alike.

The *Aqua Virgo* aqueduct collects spring water from an igneous aquifer (Pozzolane hydrogeological complex with basalts and tuffs) consisting of a complex of massive and chaotic pyroclastic flow deposits. The waters have a temperature of about 16–17 °C, and are bicarbonate-calcic with a moderate concentration of salts averaging around 550 mg/L [128]]. Other significant examples of Roman aqueducts supplied by springs include the following:

- The Catania aqueduct was 24 km long, extending from Santa Maria di Licodia to Catania at the Benedictine monastery of San Nicola. The aqueduct was one of the most demanding hydraulic engineering works made by the Romans in Sicily. The springs emerged at the base of a rock cliff of effusive basalts, and water was channelled towards the city with enough flow to satisfy the needs of the population and supply numerous baths and naumachia at that time. Today, some of the springs that supplied the city of Catania in Roman times now feed the Cherubino Fountain, which was reconstructed by Benedictine fathers in 1757 (https://www.romanoimpero.com/2019/10/acquedotto-cornelio-di-termini-imerese.html, accessed on 10 May 2024) [129].
- The Roman aqueduct of Olbia was built between the 1st and 2nd century AD. It was about 7 km long, reaching from the springs of Cabu Abbas to the baths of the ancient city via an underground pipeline. The source for these springs is a late Palaeozoic granitic aquifer.
- The Church of Santa Fiora in Tuscany was built in the 15th century during the Renaissance period. Archaeological excavations were conducted to reconstruct the original church floor, which can now be admired through a layer of glass tiles (Figure

23C), revealing the appearance of the site before the church was built and the presence of a clear, perennial spring.

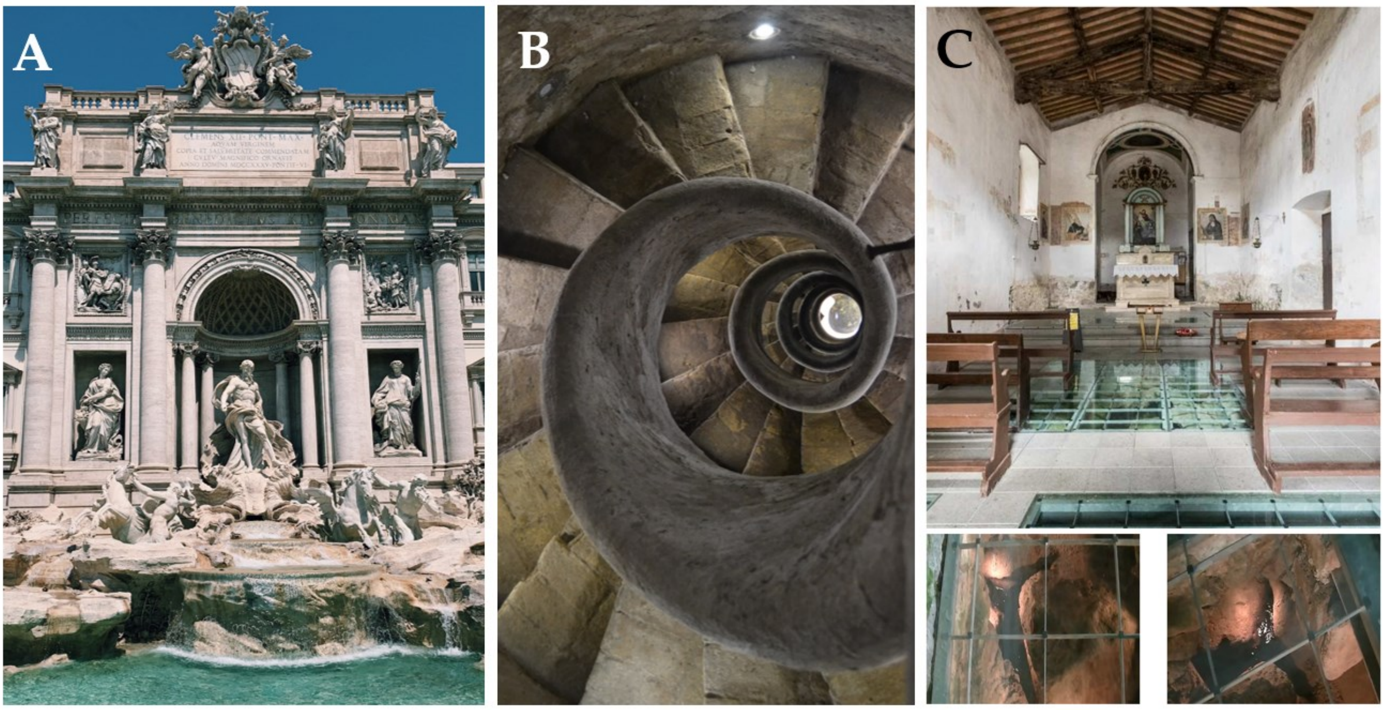


Figure 23. (**A**) Trevi Fountain; (**B**) At the top of the Spanish Steps of Piazza di Spagna in Rome a 500-years old staircase leads 70 m below to the Acqua Vergine; (**C**) The floor of the Church of Santa Fiora (15th century). The glass tiles on the floor show the presence of clear spring water with a perennial regime. Photo credits: Pexels (A), Pixabay (B), S. Segadelli (C).

Literature

Springs also had a highly symbolic value in Italian literature. The *Fonti del Clitunno* (Umbria region) has inspired artists and writers since Roman times. Throughout history, poets and writers such as Virgil, Pliny the Younger, Byron, and Carducci have been enchanted by the charm of springs. In these writings, spring water was considered the origin of every form of life, a symbol of rebirth and regeneration, a fertilizing element, and a magical and therapeutic substance. Carducci, the first Italian to win the Nobel Prize for Literature in 1906, dedicated a poem written in the autumn of 1876 titled *Alle fonti del Clitunno* to the site.

Contemporary Uses

Throughout modern times, much effort has been expended to controlling freshwater supplies to avoid water being "dispersed according to the caprice of nature". Examples of such efforts are the Peschiera-Capore and the Campano aqueducts. The first was inaugurated in 1949, with work extending through the 1960s and completion in 1980. This aqueduct is fed by the Peschiera Springs that gush from the Monte Nuria area. The aquifer feeding the springs is composed of limestone in Triassic platform facies that have been affected by karstification. Half of their flow (9 of 18 m^3/s) is captured to supply water to Rome. The Le Capore Springs have an average discharge of 5 m^3/s, flowing from a Meso-Cenozoic karstic carbonate aquifer [130]. The second tunnel, in the Campania region, is fed by Biferno Springs on the Adriatic side of the Matese massif in Molise and by Torano and Maretto springs on the Tyrrhenian side of the same massif. The Matese karst massif is composed of limestone, dolomite, and marl carbonate platform and scarp deposits from the Triassic to Miocene [131,132]. The minimum and maximum discharge recorded around Caserta and Naples by the Acquedotto Campano was 2.1 m^3/s and 5.3 m^3/s, respectively. The total length of this pipeline/aqueduct is about 580 km [133,134].

Socio-Economics

In more recent times, bottling water has become a significant industry, transforming spring water into a consumer product. Per capita, Italy is the country that most produces and consumes bottled water in the EU, with nearly 160 water bottling companies and >14 BL of water bottled per year. Meanwhile, in mountainous areas of the Italian MCZ, springs continue to represent the traditional primary source of domestic water for rural Italians. Added to the ever-increasing anthropic pressure on the nation's groundwater and springs are climate change impacts on the modern hydrologic cycle, with increased water crisis events induced by an increase in the frequency, duration, and intensity of drought. This has led to increasing awareness by the public that its freshwater supply is not infinite. Instead, it is now more clearly seen as a limited resource that should not only be considered from a utilitarian point of view, but also more holistically. Spring water is not simply an economic commodity, but is a patrimonial resource to be protected as critical "natural capital". Springs and the groundwater that feeds them provide us with a multitude of ecosystem services that, although typically undervalued, are indispensable for local and national well-being.

3.3.6. Mediterranean Basin: Greece

Springs in Mythology and Tradition

In Greek mythology, demigoddesses under the collective name of *Pigaiai Nymfai* were well-known personifications of natural forces. Not just associated with springs, they had the form of virgins who were considered the direct daughters of Zeus. Spring nymphs were partially included among the Naiads, along with those of rivers, fountains, and lakes.

The waters of the river Styx are the sources of the Krathis River in Helmos, Kalavryta District in Achaia, at an elevation of 2100 m. The waters of the Styx were associated with chthonic theological and philosophical ideas, such as those from the Eleusinian Mysteries and Orphic beliefs about reincarnation. According to mythology, Styx was an Oceanid whose palace in Tartarus was guarded day and night by sleepless dragons. It was believed that the waters of the spring came from Tartarus, and the palace of Styx. In the waters of the Styx, all of the gods swore an oath, the deepest oath a god could make, and served their sentence when they were punished. It was said that any living being that drank from this water would die, and any metal dipped in its waters would melt. It was into these waters that Nereida Thetis plunged her son Achilles so that he became invulnerable, holding him by his heel, which remained the only vulnerable spot on his body.

Legends and traditions associated numerous divine beings with water [135]. Under the oversight of Artemis, the Naiades included the Pegaiai (Pegaeae, nymphs of springs), the Krenaia (nymphs of fountains), the Limnades and Limnatides (lakes), and the Heleionomai (marshes), who were depicted as lovely women who protected spring waters. Greek *nymphaea* were religious structures constructed to honour these demigoddesses. Initially, *nymphaea* were modified natural grottos, but were subsequently constructed as sometimes highly elaborate semi-circular temples, often with fountains. This tradition was adopted by the Romans, and examples have been excavated across the Roman Empire from Türkiye to the British Isles [70]. The Nymphaeum of Jerash (191 AD) in Jordan is particularly exquisite. *Nymphaea* were typically constructed at the inflow points of Roman aqueducts, and small *nymphaea* were also built as alcoves or niches in individual houses. In addition to honouring lesser gods, *nymphaea* served the function of protecting the emerging groundwater from pollution by livestock and atmospheric impacts, much as modern springboxes do throughout the world.

Spring-fed fountains were often constructed at *nymphaea* or on the occasion of the establishment of settlements and churches, as well as upon the creation of roads.

Fountains were a main point of socialization, especially for village women. The space around them became a venue for important ceremonies and folklore events, especially when the fountain had, or was thought to have, healing, magical, or other properties, such as eugenics or eutecnia.

Many examples of springs with rich Greek histories are found in Italy, such as *Fonte Aretusa* (Arethusa Spring) on the coast of the Mediterranean in Syracuse, Sicily (Figure 24). This site has been known since the 7th century BCE when the Greeks established a colony here. Arethusa was a nymph who was turned into a fountain by the goddess Diana to protect her from Alpheus, who was pursuing her. Her story and relationship to this spring are frequently mentioned by poets, writers, and travellers over the ensuing ages (e.g., Pindalo, Ovidio, Virgilio, and Ciceron). Additional details about the site are provided in [136–138].

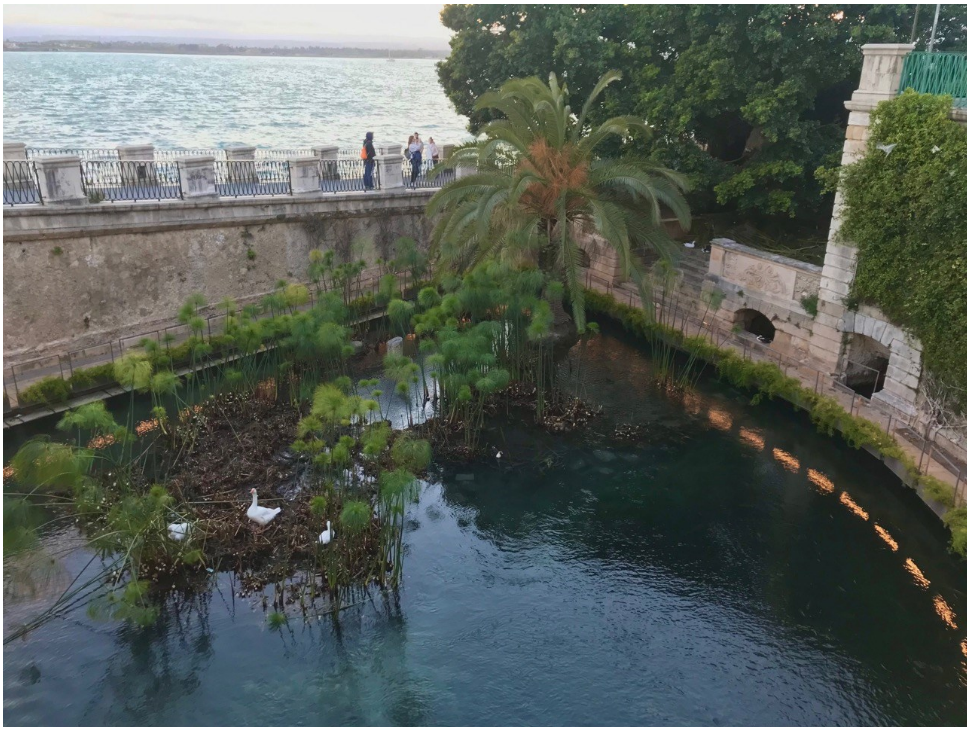


Figure 24. *Fonte Aretusa* (Arethusa Spring), Syracuse, Sicily (photo credit.: J. Corbera.).

3.3.7. Mediterranean Basin: Türkiye

Introduction

Türkiye is geologically and topographically heterogenous, spanning Mediterranean, Continental, and Oceanic climate zones. Mediterranean climate is characterised by precipitation levels < 200 mm during the summer months [139]. Türkiye's MCZ lies on the southern coastline of the Mediterranean Sea, from the Muğla to Antakya provinces. The Taurus Mountains rise abruptly from this Mediterranean coast, reaching > 3700 m a.s.l., and increase humidity in the region. As elsewhere, Türkiye's Mediterranean climate is characterized by mild and rainy winters and hot and dry summers along the coasts [140].

Structural Geology

Two main fault systems influence groundwater storage and emergence: the North Anatolian and East Anatolian faults [141] (Figure 25). Numerous hot springs arise along these faults near Muğla (Köyceğiz). Many soda springs emerge near the lakes Acıgöl and Salda, and sulphur springs emerge around Lake Burdur northwest of Burdur in the Mediterranean Region. The cities of Antalya and Mersin are rich in karstic springs (e.g., Kırkgöz, Olukköprü, Boğsak, and Aydıncık springs) [142].

Figure 25. Some spring types in the Mediterranean region of Türkiye: (**A**) Rheocrene spring in Acıgöl Lake, Burdur; (**B**) Sulphur spring in Burdur Lake, Burdur; (**C**) Alkaline spring in Muğla; (**D**) Kırkgöz spring in Antalya; (**E**) Alkaline spring in Salda Lake; (**F**) Hotspring in Muğla; (**G**) Karstic spring in Muğla. Photos credits: C.N. Solak.

History

Throughout history, hot springs have been important in Anatolia and the rest of Türkiye. In ancient times, Hieropolis (the "Holy City") was founded as a thermal spa in southeastern Türkiye in what is now Denizli Province [143]. Its buildings were primarily constructed from spring-deposited Pamukkale ("Cotton Palace") travertines in the late 2nd century BCE by the Attalid kings of Pergamom. In addition to its spa and balneotherapeutic functions, wool was scoured and dried there. Ongoing excavations at this World Heritage Historical Site have revealed Greco-Roman temples, monuments, baths, and other archaeological finds, including a *nymphaeum*. The area is also renowned for its large system of canals which delivered water to surrounding communities and agricultural fields, extending about 70 km northwest to the Büyük Maíandros (now the Menderes) River, which is spring-sourced and is the longest river to reach the Aegean Sea.

The Pamukkale travertines used to build Hieropolis provide an excellent example of interactions among tectonic and seismic forces that influence aquifer development and direct groundwater movement and emergence in springs [144]. Travertine deposition occurred in and around the Hierapolis Fault zone as a result of degassing and precipitation of $CaCO_3$-enriched geothermal water in >20 fault-controlled fissure ridges. Blocks of vertically banded fissure travertines (ornamental "Phrygian marble"), as well as utilitarian bedded travertines were quarried from the plateau downslope from the city, with each narrow quarry excavated into a nearly vertical fault fissure. As a result of its tectonic extensional setting, extant hot pools and active travertine deposition are located just downslope from the fault alignment.

Cultural Aspects

Alexandria Troas was founded close to Kestanbol Hotsprings in Çanakkale Peninsula [145]. During the period of the Ottoman Empire, the Turkish Bath practice known as "Hammam Culture" became regarded as important for body treatments. Traditional components included *kese* (a special glove for peeling), *pestemal* (a kind of traditional towel), *tellak* (a specialist trained in hammam), and olive soap [146]. Besides its health and healing properties, hammam is also important for socialization, as those who visit the hammam are refreshed and relaxed after the bath and massage. Moreover, they are able to speak about daily life events with their *tellak* during the massage.

Economics

The geothermal energy industry in Türkiye has been developing as geothermal power plants are built to produce electricity and heating systems for buildings and greenhouses [147]. The country is seventh in the world in terms of its geothermal potential [148] and about 12% of Türkiye's geothermal potential has been appropriated thus far for direct use and geothermal electricity production, with 17 cities currently heated, at least in part, by geothermal energy [143]. Lying in the Mediterranean Region, the Province of Muğla contains multiple hot spring systems, with Lakes Köyceğiz, Alagöl, Sülüngür, and Koca in Köyceğiz, as well as Fethiye-Göcek Bay [149].

Besides geothermal springs, there are many mineral springs in Türkiye due to its location in the tectonically active Alpine-Himalayan belt. Mineral water is important for health, and waters enriched with calcium and magnesium are regarded as good for bone, nerve, and muscle development [150]. Many famous mineral water companies exist in Türkiye in different regions of the Anatolian Peninsula.

Overall, water is an essential part of Turkish culture, society, and economics. For this reason, some large cities have been founded near springs. Clean freshwater is not only essential to life, but represents purity and plays an important cultural role in birth and end-of-life events throughout the Anatolian Peninsula.

3.3.8. Africa: Western Cape, South Africa

Introduction

The Western Cape of South Africa overlays some of the oldest geology in the world and is endowed with numerous cold and hot springs which have served humans and nature since time immemorial. The Western Cape is also special in a historic sense, as this is where an important economic centre and melting pot, Cape Town, arose between the pre-existing indigenous culture and the new culture infused by colonization and the discovery of the trading route to East India in the second half of the 1600s. With the naval expeditions of the time and influx of settlers—first the Dutch (the so-called *voortrekkers*), and later the British—there was an increasing need for water. This was provided early on by natural cold springs originating from the Table Mountain in the centre of the growing town, the "Mother City", or Camissa, known as the "Place of Sweet Waters" [151]. Cape Town would grow to become a major metropolis of South Africa, not only due to its maritime strategic location, but also because of its fertile lands, spectacular natural scenic beauty, water resources, and pleasant climate. The city relied on intricate capture, conveyance, and storage systems of freshwater spring flows, that eventually lost their significance due to waste, pollution, and poor upkeep. The canals fell into disrepair as modern technology for damming rivers improved, and water was increasingly developed in the hinterlands and transferred through large canals to the growing city as well as to an expanding agricultural economy dependent on irrigation [151,152].

Hydrogeology

The Western Cape Province relies on approximately 13 hot springs [153], while the city of Cape Town in and by itself has about 70 identified freshwater cold springs of variable size [154], including about a dozen larger ones, harnessed in [155] (Figure 25). The springs of both areas are of meteoric origin, associated with recharged rainfall emanating as springs via fractures, structural features, or geological dislocation zones of the hard rock formations. Cape Town groundwater and springs are generated from rainfall on Table Mountain (Figure 26a), which consists of a well-lithified sandstone located as a massive formation in the centre of the city.

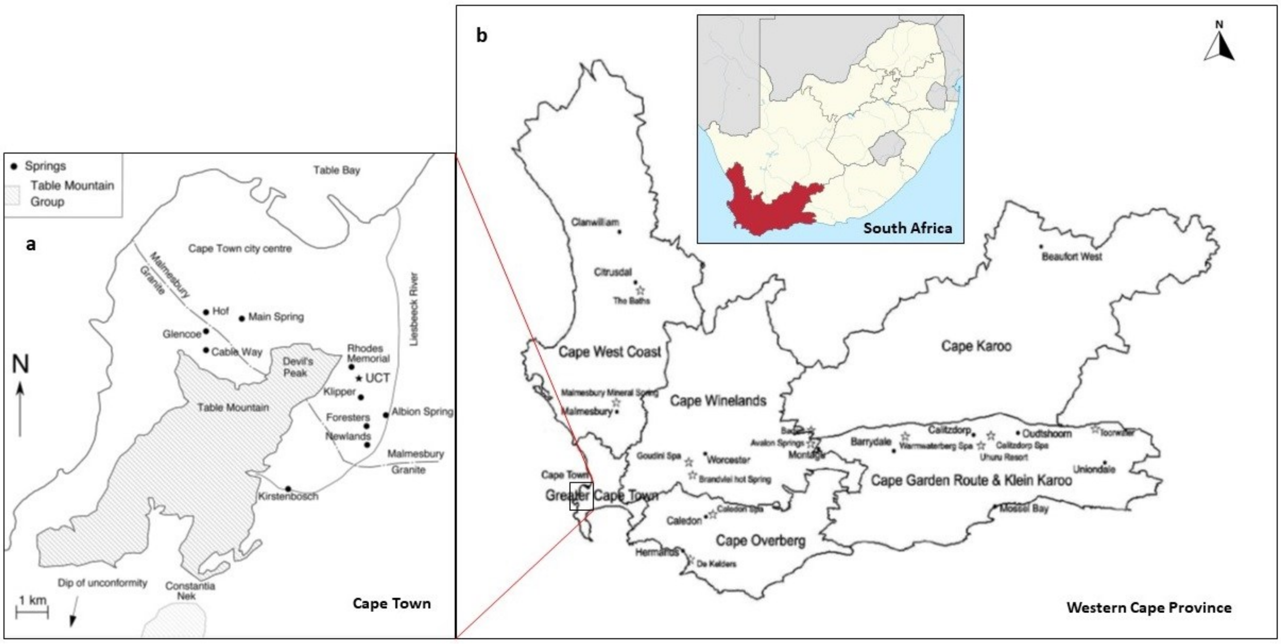


Figure 26. Location of cold springs in Cape Town [from 155 mod.] (**a**), and location of hot springs in the Western Cape Province [from 153 mod.] (**b**), South Africa.

As opposed to the cold springs, the hot springs of the province are linked to the Cape Fold Mountains, a large zone of parallel mountain ranges generally composed of sandstones and shales that curve along the southwestern coastline of South Africa about 200–300 km inland (Figures 26b and 27). The hot springs are like a string of pearls on the outer edge of this fold, indicating that the interface between impermeable underlying formations forces groundwater to emerge as springs, often in narrow fissures or sheets [156] (Figure 27). The hot water of the thermal springs is discharged from great depth, while the cold springs of Cape Town are more superficial. While the residence time of the groundwater is not well-established, it is assumed that the age of the springs partly correlates with temperature, reflecting the depth of the penetration of the water [156], implying that hot springs could be older than cold springs in similar geological settings. Water from the Cape Fold thermal springs is, however, relatively young, and the residence time of the Baths Springs is estimated to be about 2 kyr [157] (Figure 28). Most of the hot springs have moderate temperatures, with the hottest, Brandvlei Spring, reaching 64 °C [156]. Despite the longer residence times and higher temperature of the water of the hot springs, which give rise to higher levels of interaction with the aquifer material, the hot springs have low mineral content [156]. The Cape Town aquifers are mostly fresh, with good drinking water quality if protected [151].

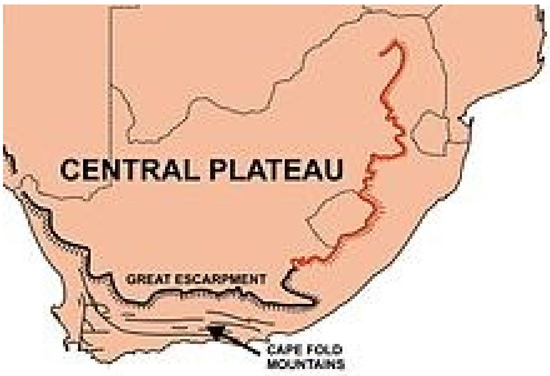


Figure 27. Location of the Cape Fold Mountains in southwestern South Africa (Source: Wikipedia, licensed under CC BY 4.0).

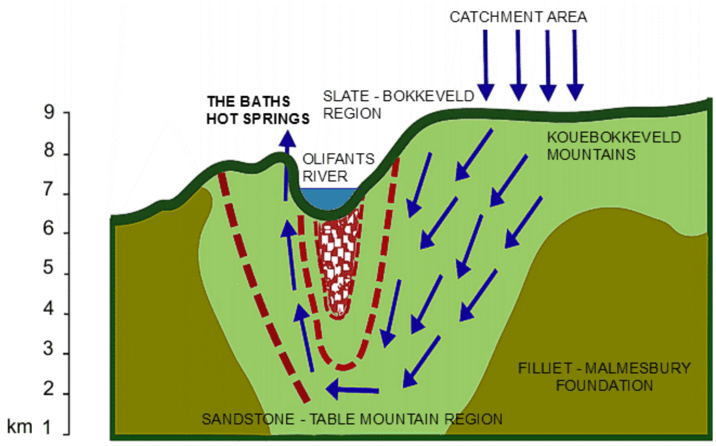


Figure 28. Diagrammatic illustration of the generation of The Baths Hot Spring in the Western Cape Province (Source: Natural Hot Springs "Hot and Cold Pools"; thebaths.co.za, accessed on 10 January 2024).

Cultural Significance

The indigenous, pre-settlement cultures of the region, importantly the Khoekhoe and San peoples, contracted into "Khoisan", reportedly discovered the therapeutic properties of the region's springs from animals, who were observed seeking shelter and refuge for healing in the springs.

Besides the importance of natural cold springs for the establishment and growth of Cape Town, the hot springs were also influential. The geothermal waters were not sought for water supplies, but for their balneotherapeutic properties. The hot springs located to the east of Cape Town rose in importance as settlers, travellers, and "Indian invalids" (those injured in East India during their posting there) took advantage of the documented healing properties of the springs [158]. Initially, these hot springs were just holes dug close to spring outlets on public land, excavated by the Indian invalids themselves. There, they could bathe and take mud baths. Eventually, those sites were developed into sanatoriums on private land, where balneotherapy businesses associated with these geothermal resources expanded over the years [158] (Figure 29). The health and wellness culture associated with mineral thermal waters that was important to the ancient Greek and Roman cultures was hence also adopted in South Africa, indirectly via the British. Over the years, this stimulated an important industry, with visitors coming to enjoy the natural springs and the pleasant Mediterranean climate of South Africa [158].

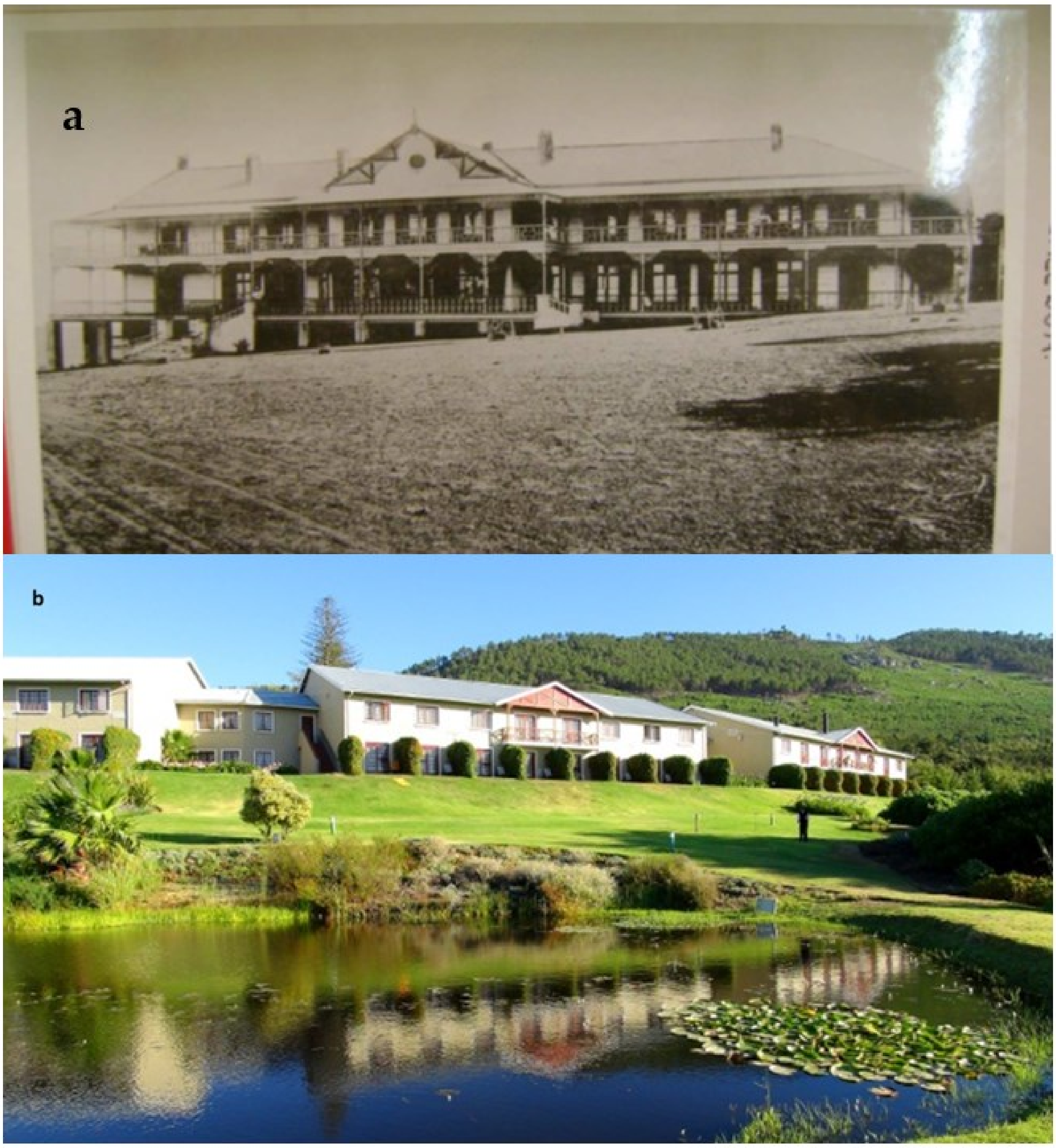


Figure 29. The Caledon Sanatorium, situated on the Caledon hot spring in the Western Cape, in 1898 [158] (**a**) and at present when it includes a hotel and spa (**b**) (Source: KAB, Jeffreys Collection, J2298, Western Cape Archives and Records Service).

Today, the hot springs of the Western Cape still play an important role in medical, health, and nature tourism, with undervalued and undeveloped potential [154,156]. These aspects of tourism can be significantly developed, both domestically and internationally. While the natural and rustic properties of springs are highly appreciated by those regularly visiting hot springs, a general consensus exists that more infrastructural improvement and additional amenities can be developed to expand visitation and enhance the visitor experience. A more concerted support to the thermal wellness industry could also spark socioeconomic development in some of the smaller communities in the region, with spill over effects to other sectors [153]. Some of the thermal springs could also serve alternative or additional purposes, e.g., for greenhouse heating or for aquaculture [156].

A cry for water was sparked with the 2018 Day Zero drought crisis in Cape Town (Figure 30), generating a discussion about the incorporation of natural freshwater springs into the public water supplies. Despite the fact that the Cape Mountain springs played a significant role in water supply during that dire drought, especially for the poor [159,160], development of these water resources was not considered a feasible path to help cover the city's water needs and avert a similar crisis in the future [154]. The amount of water produced by natural springs in the region is relatively small (about 6000 m^3/day) [145] compared to the total production needs of the city (about 800,000 m^3/day) [147]. The spring water is mostly captured for non-potable use (firefighting, irrigation, landscaping) [152] and for the most part is discharged via stormwater systems into the sea through underground tunnels in the city [154]. A significant cultural heritage which arose centuries ago is considered lost, and cultural, environmental, and human rights activists are working to meet this challenge (reclaimcamissa.org, accessed on 10 January 2024)). Groundwater from boreholes, wellfields, and private wells plays an increasingly important role in the Western Cape. The practice of augmenting groundwater through artificial recharge is increasing [161], but has uncertain impacts on groundwater supplies and the ecosystems and biodiversity they support.

Figure 30. Capetonians collecting spring water during the 2017–2018 Day Zero drought [160].

3.3.9. North-western India and Eastern Himalaya

Introduction

Mediterranean climates occur in north-western India, northern Pakistan, and elsewhere in the western Himalaya. Here, springs play an essential role in providing water for drinking, irrigation, fish hatcheries, hydrogeology, and supporting ecosystems and biodiversity throughout the Himalayas. There are roughly three million springs in the Indian Himalayan Region (IHR) [162] that serve as the source of drinking water for over 200 million people. An estimated 80–90% of the Himalayan population depends on springs for domestic water use [163]. The states of Jammu and Kashmir, Himacahal Pradesh, and Uttrakhand are known for their Mediterranean climates and extensive network of springs, numbering in the many thousands. Springs are embedded in multiple landscapes and offer a variety of ecosystem services. Historically and culturally, spring water is preferred for drinking compared to surface water because spring water is believed to be clean and pure, and have good taste and healing properties. Spring water is of great importance in guaranteeing the domestic water supplies of urban, rural, and mountain residents, and in supporting social and economic development, and maintaining ecological balance.

History and Culture

The protection of springs is not a new concept: for millennia, people and societies have managed and maintained springs according to their own needs and beliefs. The Hindu community’s religious beliefs have been a driving force in protecting springs. The Muslim community constructs mosques near springs to ensure the availability of water for religious purposes, and protects and maintains those springs. In Nepal, springs are safeguarded with stone and concrete walls and are fenced with wire and trees to restrict access [164]. Some springs are locally protected based on religious beliefs linking their origin to the Snake God (Nag). A local Kashmir term for springs is *nag*, a term related to captivating myths that add a unique cultural dimension [165]. The community fears that polluting these sacred sites could lead to disasters like landslides. Most springs associated with the Snake God are close to settlements, and their water is either pumped and stored in nearby cement tanks for distribution or directly piped to households [166]. The use of gravity-flow system (GFS) tanks to store spring water from remote springs represents an important strategy in Bangladesh’s water resource management. This approach underscores the importance of harnessing spring water efficiently to address water scarcity challenges [167].

It was formerly a cultural practice in the Himalayan region to fence springs, especially those used for drinking, bathing, or washing. Fences were normally constructed of branches, and cloth material was sometimes used to signal their location or priority for protection from livestock. This practice has now been replaced by governmental or community programs to protect water sources using concrete and iron grills. During winter in Kashmir, springs were preferred destinations for bathing and washing, as their constant water temperatures were somewhat warmer than ambient conditions. In most situations spring waters were diverted from upper slopes down to a wooden conclave (*srankut*) built for bathing. The clearing of the spring was a rural community task. A designated person would replace damaged fencing, remove litter and unwanted macrophytes, and clear out sediment for a day every 6 months. Community participation is key to these efforts, by integrating traditional knowledge with modern scientific approaches [168].

Springs hold deep cultural significance in Himalayan communities and are featured in local rituals and heritage. Springs are frequently marked by temples and stone sculptures, such as *gomuk* which resemble animal heads, particularly in the Western Ghats [169]. In the Himalayas, miniature step-wells (*naulas*) are constructed to facilitate and focus seepage, as well as to store water and protect springs. Local communities predominantly own, use, and maintain these structures as communal resources, with minimal intervention from the state [170].

Springs Distribution

The region has thousands of springs; however, exact numbers are not known. In Kashmir valley, freshwater springs are widely distributed (Figure 31 and 32a), occurring both in high altitude areas and on the plains. Across the length and breadth of the valley, there are numerous springs which provide freshwater all year long. The majority of these springs are small and occur on private land. This has led to springs being modified, polluted, and overlooked in conservation and management planning. Many springs have vanished over the past few decades, as witnessed by the local communities, and the present-day distribution and number of springs is less than in the past. However, the extent of these losses is not known. Despite a long history of spring research across globe, including in the Himalayas, and a growing intensity of scientific research [165,171] and public concern, an inventory and classification of spring ecosystems in the region is lacking.

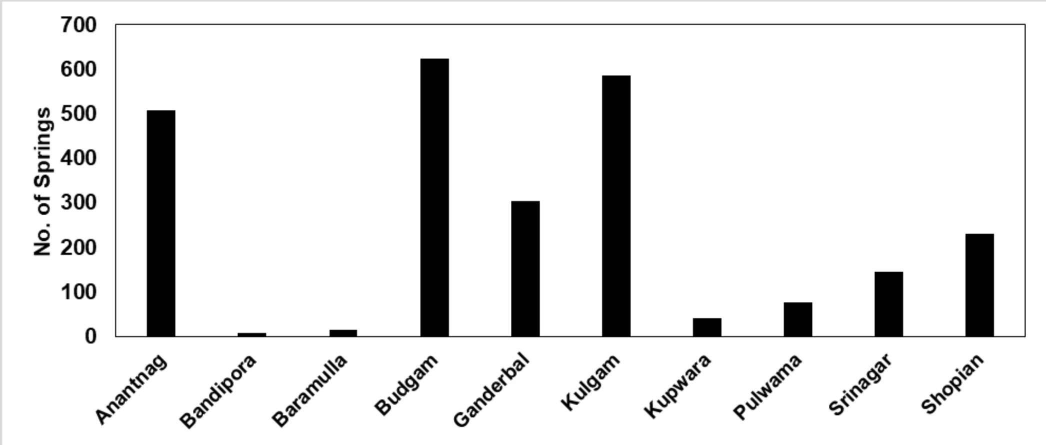
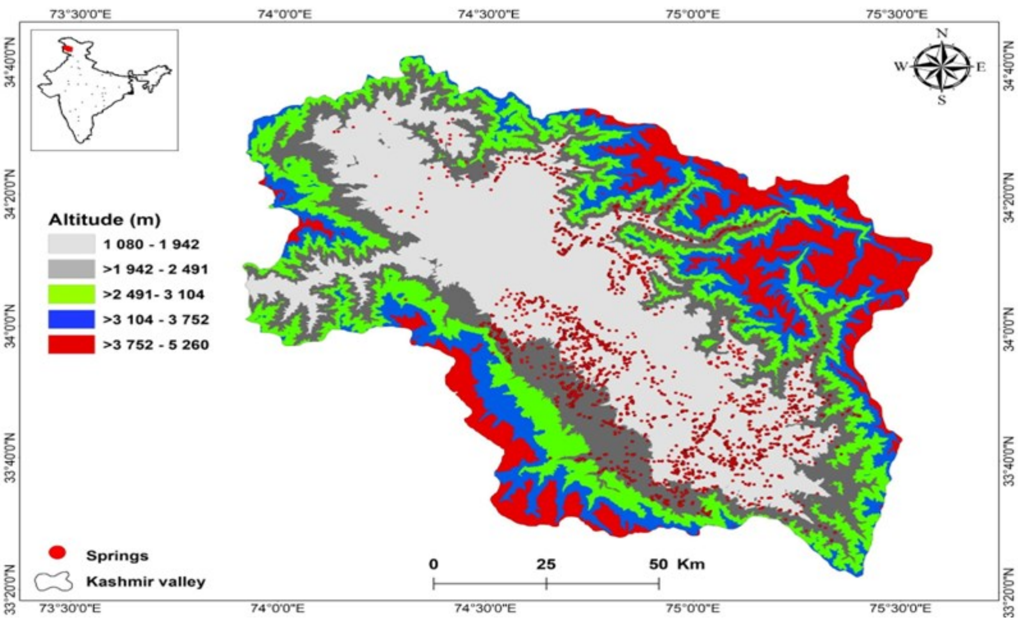


Figure 31. Distribution of springs in Kashmir valley by district. Figure reprinted from [171] under the Creative Commons Attribution License 4.0.

Bhat et al. [172] provided a comprehensive database of 254 managed springs distributed throughout the Kashmir Valley. An inventory by the Public Health Engineering Department Jammu and Kashmir consists of springs used for supplying and having potential for drinking water supply, and does not report on small springs. The latest spring inventory conducted by Bhat et al. [173] revealed more than 3000 springs from the different districts in Kashmir Valley (Figures 31 and 32). A closer look of those data revealed that more springs are observed in the Budgam, Kulgam, and Anantnag districts (Figure 31). Springs have been documented in the Tawi basin Jammu region (Figure 33), including hot springs in Ladakh (Figure 34).



(**a**)

(b)

Figure 32. (a) Spring distribution in Kashmir Valley; (b) Examples of springs from the Kashmir Valley.

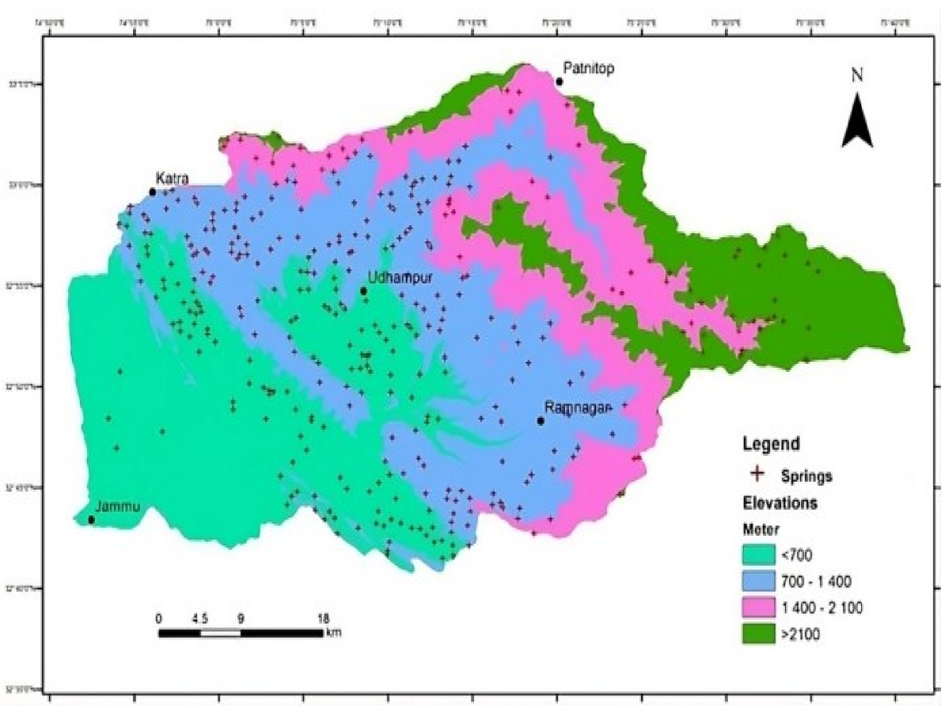


Figure 33. Spring distribution in the Tawi basin of Jammu.

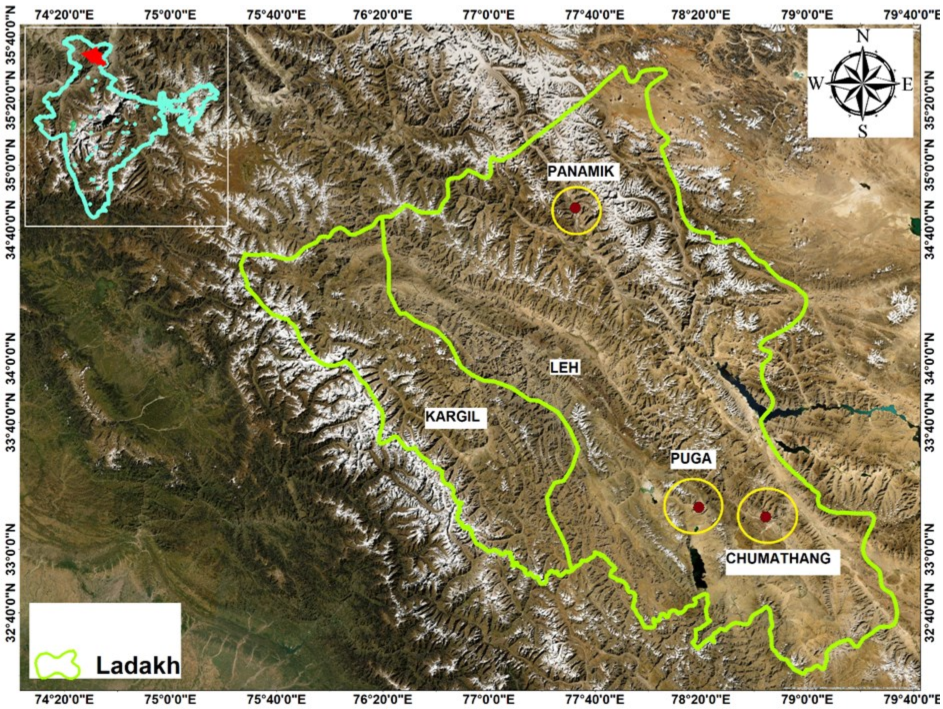


Figure 34. Distribution of hot springs in Ladakh Himalaya.

3.3.10. Economic Importance

Many water supply schemes in Kashmir are sourced from springs, such as those in Verinag, Kokernag, and Achabal, and springs are the preferred water for raising trout in Kashmir (Figure 32b). These springs are known as *dhara*, *mool*, and *kuan* in the central and eastern Himalayas and *nag*, *nagin*, *chashma*, and *naula* in the western Himalayas. Springs in these regions are important not only for utilitarian purposes, but also in relation to religious and cultural activities. In addition, springs serve as tourist destinations for nature lovers from all over the world. Many fish farms in Kashmir rely upon springs, and many villages obtain most of their water supplies from springs. Popular Kashmir Valley springs include Cheshma-Shahi, Verinag, Kokernag, Achabal, Panzat, Hemail-Nagraj, and others that are protected as parks and are important recreational sites. An estimated 30% of the population in the Kashmir valley depends on springs for daily use, and in some of the mountainous regions of the valley, springs are the sole source of drinking water. Although most springs are small, they are abundant and have high water quality.

3.3.11. Management and Protection

Improved management and protection of the region's springs is increasingly recognized as an important need. The Kashmir Himalaya is known for its abundance of freshwater springs and approximately 51% of Jammu and Kashmir villages are situated near springs [162]. Traditional knowledge and cultural practices can help contribute to the conservation and sustainable use of springsheds [162–164,166–170]. Local communities have implemented protective measures such as fencing and concrete structures to protect the springs from contamination with organic matter and allow water accumulation in pools for washing and irrigation. Additionally, local residents hold springs in high esteem, attributing sacred and healing properties to them, and constructing shrines around certain springs. Rural Development Departments are responsible for overseeing maintenance of these sacred sites. Notably, Mission Amrit Sarover actively concentrates on the rejuvenation and revitalization of these critical springs.

Despite the great importance of springs, little attention has been paid to their management and conservation [174]. Large scale land-use and cover changes, massive deforestation in the catchments, and infrastructural developments have disrupted hillslope hydrology and led to the degradation and loss of springs. Furthermore, the use of pesticides and fertilizers in the horticultural sector is an emerging concern. During the last few decades, organic pollutants, excessive water withdrawal, encroachment, and climate change have been the major threats to freshwater springs in the Kashmir valley [175,176]. Reports on reduced spring discharge are a grave concern because the human populations in these districts are often entirely dependent on spring water for drinking and other purposes.

3.3.12. Australia—Southwestern Australia

Australia has largely uncoordinated drainage across the southern and western two-thirds of the continent west of the Murray-Darling Basin, with a Mediterranean climate. Rivers are usually short and coastal, as much of the continent lacks high mountains. The prolonged lack of inland drainage has led to the accumulation of salt in catchments, and chains of salt lakes along paleoriver drainage lines are a common feature.

Consequently, springs are widely scattered in south-western Australia. Only a few place names include the word "spring", such as Three Springs north of Perth. Springs are virtually absent from southern Western Australia except near Bullsbrook to the north-east of Perth and at Gnowangerup north of Albany. Today, water sources for human consumption come predominantly from underground aquifers and surface pools along rivers, creeks, and lakes. Recently, the desalination of sea water has been adopted to provide the growing metropolis of Perth with fresh water.

The W.A. Naturalists Club reports that the Swan Coastal Plain mound spring on the Gnangara mound, west of the Ellen Brook and the Darling Scarp, is situated over a series of aquifers (including the Yarragadee) from which some of Perth's potable water is extracted in times of drought (https://www.wanaturalists.org.au/mound-springs/, accessed on 15 December 2023): "This mound spring site has broad zones of peat ~100 m wide. It has eight vegetated springs over an area covering just 21 ha from Bullsbrook to Mundijong. The mound springs have a tree story of Swamp Banksia (*Banksia littoralis*), Paperbark (*Melaluca preissiana*), and Flooded Gum (*Eucalyptus rudis*), with lower cover stories composed of ferns and sedges, and amongst the non-vascular plants are bog clubmosses and liverworts". This plant community is threatened.

Springs are known from right in the heart of Perth, for example at the bottom of Spring Street, at a place known to the local Noongar Aboriginal people as *Goondinup* (from *goodinyal* = cobbler fish). This is an important camping and fishing place. Less than a kilometre further west, at the foot of the Kings Park escarpment adjacent to the Swan River, Kennedy's Fountain was another important source of fresh water for drinking, and still flows today. This fountain is significant to the Aboriginal people because it is the home of the mythical Rainbow serpent *Wagyl* of the Whadjuk Noongars. It became Perth's first public water supply fountain.

On Western Australia's south coast, *beeliar* (a word used both for fresh water and mother's milk) constitutes one of two key attributes in Noongar culture for life (Knapp cited in Silveira [177]). Perhaps the most significant testament to the ongoing cultural significance of springs to the Noongar people in southern Western Australia is the aptly named *Wagyl Kaip* or rainbow serpent's water (Figure 35). The *Wagyl* (strictly *waar* = breath, and *karl* = fire) is the ancestral being that formed landscapes and waters across Noongar *boodjar* (country). The *Wagyl Kaip* native title agreement area embraces six of Tindale's [178,179] dialect groups—all of the Minang, and parts of Koreng, Kaneang, Wilman, Wudjari, and Pipelmen. A seventh group, not recognised by Tindale [179], the Mirningar Bardok, has lands overlying most of the *Wagyl Kaip boodjar* (e.g., Thieberger [180]).

Regarding springs, great cultural significance is placed on the original *Wagyl Kaip*, a vital water source named Vancouver Spring by *nydiyang* (white people) that sits adjacent to Frenchman's Bay in King George Sound flanked by *Kinjarling* (Albany—Figure 35). Inland people call the *Wagyl* "*Madjit*", so *Madjit Kep* is also used for the spring, but the *Merningar* apply *Madjit* (strictly *Maartyuirt* = hand white) to the white pointer shark. *Wagyl kaip* has always been a vital water supply going back to the earliest people, the *Kalamia*, who lived at *Kinjarling* when forced upslope to the *Kalamia* Hills (above today's Goode Beach) by rising sea levels. Wagyl Kaip Spring became Albany's main water supply soon after settlement in 1826, providing water for whalers for steamships from the mid-1800s.

There are other forms of spring-like water sources on Noongar *boodjar*. The Night Wells fill up only at night and drain away in daylight. One such well near Borden is called *Kep Waam Win Barkep* (=water, to and fro, being that which [is] rock water) by the Goreng people. The creek bed is salty, but overlying granite pools (*gnamma*) filled up with fresh water at night until *nydiyang* applied explosives to enlarge the *gnamma*. The Knapp Merningar family always used night wells, ubiquitous along the southern coast, to avoid possible poison placed in open-water ponds and pools.

The town of *Gnowangerup* is famous among Noongars for its elevated springs known as *Gnowwanyirup*. *Gnow* is the mallee fowl (*Leipoa ocellata*), *wan* means "nest", *yir* means "elevated", and *up* is "place of". The allusion is evident when one encounters a mallee fowl nest (Figure 35). Today, the spring's emergence and downslope movement of water are constrained by concrete works.

Figure 35. The *Wagyl Kaip* and Southern Noongar Indigenous Land Use Agreement for Native Title Settlement, in geographical context, showing locations of *Wagyl kaip* spring and *Gnowanyirup* spring. Photo credit: S.D. Hopper.

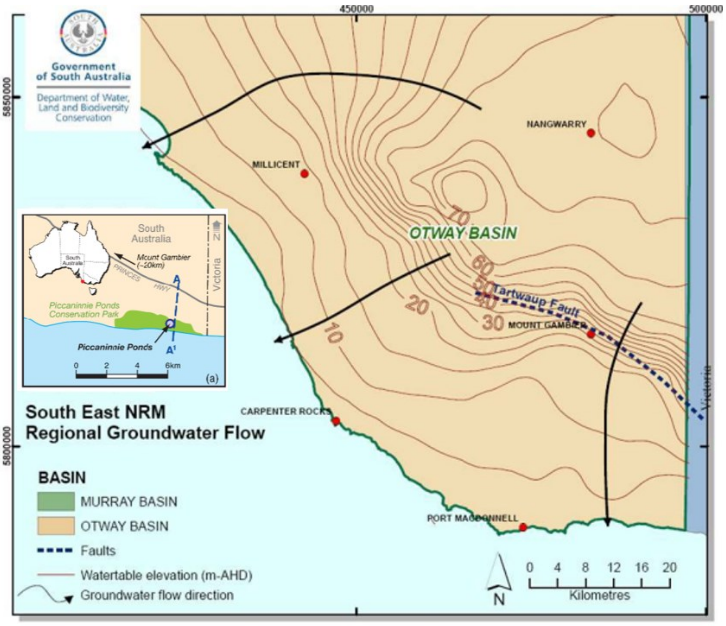
3.3.13. Australia: Southeastern South Australia Limestone Coast

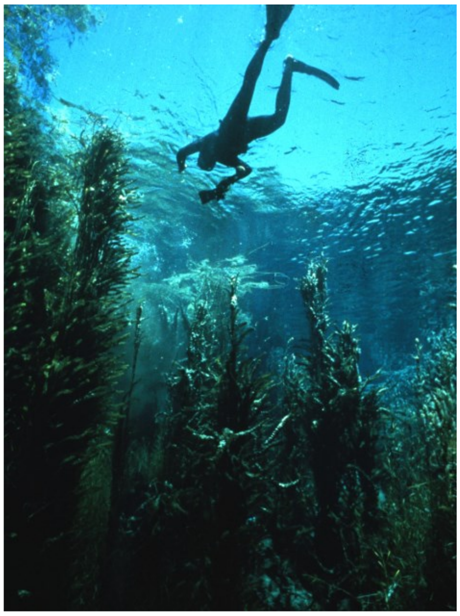
The Southeastern region of the State of South Australia is a vast 200 × 100 km limestone karst field within a climatic zone designated as Mediterranean—hot dry summers extending into autumn (December–May) and cool wet winters extending through spring (June–November). The Miocene limestone plain there has been slowly uplifted for 15 Ma from the Southern Ocean floor to an elevation of 1–150 m a.s.l. It has little surface cover apart from thin sandy or terra-rossa soils and a series of 13 Quaternary sandy-limestone ranges parallel to the coastline, reflecting the last 13 interglacial highstands of the sea between the southern Quaternary Ice ages [181]. The limestone plains have over 1000 recorded caves, mainly along the three dominant fault lines. Some of these are freshwater cenotes—striking karst features formed by hypogenic processes associated with local Pleistocene volcanoes [182]. Rainwater enters the limestone across the region through karst fractures, "Runaway Holes", dolines, and general surface limestone exposure. The fresh groundwater aquifer of the regional Gambier Limestone flows coastward (Figure 36) and discharges through a number of coastal karst springs, the largest of which are Piccaninnie Ponds and the triple Ewens Ponds. Both are Conservation Parks, and the former is a RAMSAR site (Figure 35). Their discharge ranges from 27,000–120,000 and 105,000–236,000 m^3/day, respectively [183]. Small additional freshwater springs emerge from local beaches at low tide.

The springs occur within 1–2 km of the coastline and emerge from small joints, a series of dolines and two large rifts in the limestone. Prior to the arrival of Europeans, Indigenous Australians of the region—the Boandik People—used the fringes of these springs and the seasonal wetlands associated with them as rich sources of food. One archaeological site at Wyrie Swamp (a wetland further inland on the karst) revealed a transient occupation site containing several intact wooden boomerangs from a period 10–6000 years ago [184]. One hundred kilometres east of the karstfield, the Gunditjmara people constructed fishing races from scattered lava stones to form eel traps at Budj Bim (Lake Condah), now a World Heritage Cultural Site for its ancient continuous aquaculture practice of a similar age to Wyrie Swamp. Some caves only a few kilometres from the springs have finger fluting, petroglyphs, and flint mining marks on their walls near groundwater pools within the caves [185].

When Europeans arrived in the region in the 1840s, they found much of the lower limestone plain country waterlogged for half of the year, with extended ponding trapped behind the Quaternary dune ridges for distances of many tens of kilometres. Over a century, they cut transverse trenches to drain this surface freshwater directly into the sea in order to create year-round arable land [186]. This has resulted in a regional lowering of the water table, a great reduction in the discharge rate of the springs, and some saltwater intrusion in certain springs very close to the coastline. The drains still exist today, but are now controlled and managed, and a regional Water Allocation Plan monitors annual limits on groundwater extraction for agriculture, forestry, industry, and domestic supplies, as the regional landscape is very productive [187]. The dumping of town and farm rubbish in caves, cenotes, sinkholes, and springs occurred for over a century until awareness of the impacts of groundwater pollution arose in the 1970s, leading to environmental legislation strictly controlling the disposal of all forms of waste into the ground.

The caves, cenotes, and springs are very popular with visitors, snorkellers, swimmers, and divers, who contribute to an important and distinctive local tourism industry. Speleologist mapping, underwater scientific observations, and ecological studies have contributed to a wider understanding of the coastal spring environment, including rehabilitation works to restore some previously drained coastal peatlands and their terrestrial and aquatic environments [188]. In our current world of reducing rainfall patterns in this MCZ, we are increasingly mindful of the Australian Aboriginal expression and philosophy of "Caring for Country".





(**A**) (**B**)

Figure 36. (**A**) Coastal Springs Zone, South-eastern South Australia [183]. (**B**) Snorkeller at Ewens Ponds Karst Springs. Photo credit: T. Drew.

3.3.14. United States: California

Introduction

The United States has many large and small cities that include "spring"' in their name. Famous recreational spring attractions are found in cities in New York (Saratoga Springs), Virginia (Warm Springs), Arkansas (Hot Springs), and elsewhere. However, none of these popular springs have as many cultural associations as does the Mediterranean region of California. The unique geology of this area has resulted in all of the spring types long ago described for the whole state [189], including hot springs, carbonated springs, sulphur springs, saline springs, and springs described by their predominant and sometimes unique mineral components such as magnesium, iron, and lithium. The physical and consequentially biological diversity results from tectonic activity in this region, with the resulting waters rich and diverse in mineral composition [190]. Gasith and Resh [53] described the Mediterranean climate region of California as including coastal areas, the Central Valley, and the foothills of the Sierra Nevada. However, most of the information about cultural activities associated with springs comes from spring habitats located in the Coastal Mountains of this region.

Indigenous Use

Human use of the diverse springs in California's MCZ extends back at least 12,000 years when native Americans initially moved into Coastal California [191]. Folklore, spirits and deities, healing practices, and even the occult have been associated with these springs by various groups of indigenous people. With the arrival of Europeans, water diverted from springs enabled the expansion of agriculture through the irrigation of fields during the dry season, and eventually springs became a source of recreation, healing, and entertainment. In the 19th century, recreational and health resorts were developed in California's coastal region, but these declined in use and popularity by the early to mid-20th century. Today, the revival of interests in springs are often centred on alternative healing approaches emphasizing health cures and meditation practices [192], luxurious relaxation [193], and even centres for recovery from drug addictions [194].

The traditions of ancient people have often centred on springs that had certain attributes that made them sacred. Anthropological evidence has suggested that for many native Americans, waters emerging from springs were viewed as coming up from the centre of the earth. Thus, they provided a window into the nether regions of their universe. For some groups of native Americans, hot springs were thought to be warmed by the breath of the "great spirit" and therefore were regarded as being especially sacred.

California springs have been viewed to be sites where powers of rejuvenation, cures, and spiritual activities occur. Springs contained magical beings and spirits who could both heal and destroy. The process of entering into spring waters was shrouded in ceremonial practices, decorum, and respect. In the Coastal region of California, the Coastal Miwok people were well studied by Alfred Kroeber [195] and their use of the springs has been described in several sources (e.g., [196,197]). The Miwok used areas surrounding some springs as seasonal camps. For them the springs also provided paths to healing and spiritual realms. Men of some tribes built dams and diversions to focus flow from hillside springs and created pools for bathing.

Klages [197] describes the way rituals were conducted at Harbin Spring, which is located in the Mediterranean-climate coastal region in Northern California: "To a shaman, the waters of a hot spring were an entrance way to the underworld. In a trance state, induced by meditating on such a point of entrance—a natural tunnel, rock crevasse or spring—the shaman could travel from the material world to the spirit realm. There he could talk to the spirits and do healing work which, when returning to a non-trance state, he brought back to the people of his tribe. Since these natural openings to the spirit world were considered to be rare, the springs were a very special and sacred point in the material world." Sick tribal members were bought to the springs for healing. Today, the use of spring water for health purposes is referred to as balneology, in which natural springs are used for the prevention and/or cure of various maladies, along with maintenance of overall mental and physical health. In many European countries, these "cures" are at least partially funded through government health support. However, in the United States balneology is considered as "alternative medicine", requiring private support rather than coverage through federal or personal insurance.

Multiple tribes often used the same camps and springs. Klages [197] suggested that Harbin Spring, described above, was a place of peace and healing for several coastal tribes such as the Pomos and Wappos, who often shared the same springs. However, while the springs were used year-round, it is not known if different tribes shared the same springs at the same time, or bathed with only their own tribal members, and whether genders were mixed when using the springs. Similar encampments were made by the Patwin and other tribes at nearby Wilbur Hot Springs, which is currently a flourishing resort.

History

With the arrival of the Spanish settlers and the establishment of missions in the coastal mountains of California in the mid-18th century, the culture of the indigenous people of the Mediterranean region of California was greatly altered and sometimes lost. This was also true for many of the ceremonies and activities conducted in springs as well. At this time, whole villages of Miwoks and other native Americans were moved away from their homelands and settled in Catholic missions. This resettlement of indigenous people opened land for large Spanish ranches and settlements, and provided a localized workforce for grazing livestock and agriculture [198]. Conversion to Christianity affected the traditional lives of the members of these ethnic groups, as well as reducing the outward expressions of spirituality they associated with springs.

The discovery of gold in the Mediterranean-climate region of California in 1848 led to huge increases in the population of San Francisco and eventually led to the development of many mining camps and new cities in Northern California. Some of the immigrants to the region, either through mining success or entrepreneurship, became members of the middle and upper class, and sought new and unique leisure activities.

In the 1850s and 60s, well over a score of resorts were built around springs throughout coastal California (e.g., [199]). These centres of relaxation may have been influenced by the popularity of such facilities in the eastern United States (e.g., Sarasota Springs in New York, Sulphur Springs in west Virginia, and Hot Springs in Arkansas), as well as in Europe (e.g., Baden-Baden in southwestern Germany, and many resorts in Italy). These resorts combined relaxation and access to springs for "taking the waters" and often were accompanied by the availability of restaurants, gambling, and alcohol, in addition to the perceived health benefits from soaking in the springs and drinking the water. The rise of California resorts in some ways resulted in the return of these springs being viewed as important amenities of nature and perhaps, at least to some extent as centres of spirituality and, at the same time, profitable businesses.

Famous spring resorts built at this time in coastal California included Vichy Hot Springs, opened in 1854 and popularized by the patronage of writers, such as Mark Twain and Robert Louis Stevenson, who described the "bubbly champagne waters" emanating from these springs. Newspaper accounts of visits there by US Presidents Theodore Roosevelt and Ulysses S. Grant increased public awareness of them as fashionable resorts and "places to be". The springs at Vichy have only moderately warm temperatures, ~32 °C, but purportedly had curative power for nervous disorders, and heart, stomach, and kidney problems.

Spring resorts advertised the unique chemistry of their waters. The springs of Wilbur Hot Springs had high sulphur concentrations whereas those of Indian Spring were famous for mud baths where volcanic ash and water were mixed in a slurry in which patrons were covered in mud up to their necks! Slogans, such as "waters like no other in the world" were used to popularize the resorts. Indian Springs is one of many popular springs in Calistoga, California. Reportedly, the name of the city was a slurred pronunciation for Saratoga, the famous New York spring resort. Tassajara Springs and Esalen springs, both sulphurous springs in the Big Sur mountainous region of the coastal area, overlooked the Pacific Ocean. There, the waters and the magnificent views drew people from San Francisco and Los Angeles. They are still popular sites for meditation, retreats, and seminars on living alternative lifestyles and enhancing health.

The coastal California resorts have many popular culture anecdotes associated with them. The Geysers Hot Spring Resort was owned by two brothers named Curry, and it was a very successful operation in the late 1800s. However, a feud caused them to split as partners with the older one insisting on taking this successful Geysers resort as his own, and to turn concession rights for an area in the Sierra Nevada called Yosemite Falls to his younger brother. The Geysers is long gone as a resort and now the site of extensive geothermal energy development. The Curry Company still operates concessions and housing at the hugely successful Yosemite National Park.

During the early decades of the twentieth century, these resorts became dilapidated, often burned down in dry season fires, or were simply abandoned. The influx of workers to the San Francisco Bay area in the 1940s increased use of these resorts as weekend-holiday centres because of their proximity to that city. Often, they were used by certain groups, such as recent Italian immigrants, as places to socialize and even to find spouses of similar backgrounds. The facilities of one resort, Byron Hot Springs, was turned into a prisoner of war camp for captured German officers during World War II. However, by the 1950s the popularity of spring resorts in the Mediterranean region of California had waned. Stories about them were told to subsequent generations but because of the deterioration of facilities or new emerging interests among younger people, their popularity faded into the past.

The 1960s were a time of revolutionary ideas and changes to lifestyles in the United States because of the upheavals of the civil rights movement, Vietnam-War protests, and new views of life choices. California, and especially San Francisco, became the centre of many of these changes. The "Hippie Movement," "New Age Movement," the "Summer of Love," and the "Human Potential Movement" were all centred in California's

Mediterranean climate region. Even when in dilapidated condition, many old spring resorts often were occupied by religious cults and became communes. Gurus, from elsewhere or locally produced, attracted young people and the use of psychedelic drugs became commonplace in these spring-dwelling communities.

However, entrepreneurs also saw the chance to capitalize on these movement and many of the resorts, such as Wilbur Hot Springs and Harbin Hot Springs were reconstructed or upgraded and opened for both bathing and relaxation and health purposes. Typically, these resorts were and continue to be "clothing optional", but they also became popular for other activities. For example, Wilbur Hot Springs opened a "Cokenders" residence program to treat clients with drug addiction [194]. More recently, these resorts are the sites of "celebrity-chef" weekends where food prepared by famous chefs are centrepieces of attraction, along with the springs themselves.

Some resorts were rebuilt as luxury spas [193–200]. New facilities were created, sometimes in rustic but more often in modern-resort style, and natural spring pools were sometimes diverted into modern swimming pools. Meditation programs, yoga, and various massage treatments were offered. One resort features watsu massages that are conducted with the client held by a masseuse or masseur who uses water movement to do the actual massage [197]. These specialty treatments became popular features of the modern spring resort and draw large crowds.

Hot tubs originated in Northern California and mimic the practice of bathing in hot-spring waters. The company that first developed these items was in the small California community of El Cerrito by a company that previously specialized in producing irrigation pumps. Today, the name of the founders of that company, the Jacuzzi family, is the name that is synonymous with hot tubs. These relaxation devices are often associated with the "California lifestyle" but are also popular in private homes and hotels throughout the USA and worldwide.

Indigenous peoples used springs for health and spiritual practices for thousands of years. These attributes of spring water have now been reinstituted in the commercial practices at the spring resorts of today. With the anticipation of more leisure time from shorter work weeks, less commuting time, earlier retirement, and interest in alternative health cures, the use of springs in the Mediterranean region of California will certainly persist and likely even expand in the future.

Bottled Water

Drinking water from various springs in this Mediterranean-climate area of California has been a millennial-long practice, and it is typical for brand names to specifically mention the springs in the coastal region from where the water is sourced. Calistoga, for example, the city where many of the spring resorts were originally located and have now reopened, is just one of many examples of this capitalization on the mystique and names of specific springs. These location-labelled bottled waters are popular, even where local drinking water is of high quality and taste [201,202]. Some plants in California even use filtered tap-water as their source of their bottled "spring water". Of course, on a per volume basis, the cost of bottled water from these springs far exceeds that of gasoline!

Energy from Hot Springs

Hot spring areas also became important as sources of geothermal energy for the production of electricity. Fields of hot springs and fumaroles (steam releases from springs) in California have attracted many entrepreneurs and companies interested in geothermal energy production [203]. Hopes were high for this alternative source of electricity. For example, in the late 1970s, it was anticipated that geothermal sources would be sufficient to supply 10% of all Northern California's electricity requirements. However, the geothermal fields soon became overexploited and the anticipated energy production has never been realized.

The largest geothermal energy site in the USA is The Geysers Geothermal Field, an 80 km^2 valley located 120 km north of San Francisco, and it supports 18 geothermal energy production facilities. However, the name "The Geysers" is a misnomer: no natural geysers are known in California. Energy at these geothermal plants is primarily produced directly from steam directed into turbines. Many geothermal plants re-inject used groundwater back into the aquifer. At The Geysers, treated wastewater from the nearby City of Santa Rosa is injected back into aquifers to replenish diminishing groundwater supplies.

Potential impacts of geothermal development in the area include air pollution and also water pollution resulting from the release of condensed spring waters from deep under the earth's surface, which has a chemical constituency greatly differing from those of surface waters [204]. Many of the biological effects are the result of thermal rather than the chemical attributes of the geothermal effluents, but the latter can have specific impacts because of the uniqueness of the water's chemical composition.

Biology

The spring areas of California's Mediterranean region are also known for their endemic biological fauna. One species of insect, the Wilbur Springs Shore Bug (Hemiptera: Saldidae—*Saldula usingeri)* was the first aquatic insect proposed for listing as a U. S. Federal Rare and Endangered Species [205] and other biota occurring in California springs warrant consideration for protection because of their endemic status, which is linked to the unique water chemistry of specific springs [205].

3.3.15. United States: Nevada-Moapa Warm Springs

Introduction

More than two dozen warm springs arise in the uppermost portion of Moapa Valley northwest of Glendale in Clark County, southern Nevada USA. These springs emerge at the terminus of Nevada's intermittent White River from groundwater that has travelled >200 km beneath 11 endorheic watersheds over 10,000 years [206]. Those springs provide baseflow to the 51 km-long Muddy River [69]. Originally a tributary of the lower Virgin River, it now flows into the Overton Arm of Lake Mead reservoir. The Moapa Warm Springs are renowned for supporting a diverse suite of endemic fish and aquatic invertebrate species, and for their peculiar management history.

Archaeology and History

With archaeological remains in the region dating to >8000 years ago, the landscape was occupied in pre-historic times by hunting and gathering early Desert Archaic peoples [191]. The excavation of a corn cob and other archaeological remains dating to about 200 CE indicate an early start for agriculture in the region, which likely helped support the Lost City several tens of kilometres downstream, a large settlement of Uto-Aztecan western Early Pueblan culture [207]. The region was abruptly abandoned about 1200 CE, and the region subsequently colonized by the Shoshonean Nuwuvi (Moapa Band) of the Paiute Tribe. Spring Rock Shelter in Warm Springs may have been used by the Band to avoid capture by Spanish slavers.

Explorer Antonio Armijo linked the Northern Route of the Old Spanish Trail in the vicinity of Moapa, helping develop a trade route from Santa Fe, New Mexico to Los Angeles, California. That route passed about eight miles southeast of Moapa Warm Springs and from there went on to Mountain Springs Pass through the southern Spring Mountains on what is now the west side of Las Vegas. The region was opened up to settlement after it was accessioned to the United States in 1846. Mormon settlers moved into the region and began farming and ranching after about 1850. At that time, an outlaw from Texas named Alexander Dry, who raised stolen cattle, became the first rancher in the area. Following the settlement of the valley by Mormon farmers in the latter half of the 19th Century, the Nuwuvi Band was provided with a reservation there. At the beginning of the

20th century two large ranches occupied the area, and they were merged in 1950 to form Francis Taylor's Warm Springs Ranch. During that interval, *Washingtonia filifera* fan palm trees, which are native to the California desert but not to Nevada, were introduced.

Part of the area was purchased by Howard Hughes in 1971, who continued agricultural activities and also built a resort, complete with showgirls and spring-fed swimming pools. After Hughes passed away in 1976, the Mormon Church purchased the ranch, retaining a 30 ha parcel as a retreat, but subsequently selling 494 ha to the Southern Nevada Water Authority in 2007, which named their new holding the Warm Springs Natural Area. Bob Plummer of Las Vegas had purchased a 40 ha parcel containing warm springs and constructed the Desert Oasis Warm Springs Retreat as a family-friendly resort, which operated until 1994. A large portion of the valley, including Desert Oasis and the Mormon retreat were burned in a wildfire that year and again in 2010. Del Webb purchased the property in 1997 and transferred ownership to the US Fish and Wildlife Service as part of the Moapa Valley National Wildlife Refuge to help protect the sensitive aquatic species there.

Springs Distribution

Six major spring complexes occur in the valley headwaters, including: Cardy Lamb; Baldwin; Big Muddy (on the 30 ha Church of Jesus Christ of Latter-day Saints retreat); and three complexes on the Warm Springs National Wildlife Refuge (the Plummer, Pederson, and Apcar complexes). These warm (non-thermal), mineral rich springs support many unique, unusual, and some endangered species, including the following: fish—the only populations of federally Moapa speckled dace (*Rhinichthys osculus moapae*), Moapa White River springfish (*Crenicthis baileyi moapae*), Moapa Dace (*Moapa coriacea*), and Virgin River Chub (*Gila seminuda*; in Muddy River); aquatic Mollusca—Moapa Pebblesnail (*Pyrgulopsis avernalis*), Moapa Valley Pyrg (*Pyrgulopis carinifera*), and Grated Tryonia (*Tryonia clathrata*); aquatic Hemiptera—Moapa Naucorid (*Limnocoris moapensis*; Figure 37), Pahranagat Naucorid (*Pelocoris biimpressus shoshone*), Western Naucorid (*Ambrysus mormon*); aquatic beetles—Warm Springs Crawling Riffle Beetle (*Haliplus eremicus*), Moapa Riffle Beetle (*Microcylloepus moapus*), and Moapa Warm Springs Riffle Beetle (*Stenelmis moapa*); terrestrial insects—MacNeill Sooty-winged Skipper (*Hesperopsis gracielae*); and the only population of Limewater Brookweed (*Samolus ebracteatus*) known in the Colorado River drainage [208]. In addition, six Neotropical migrant bird species, seven bat species, and Desert Tortoise (*Gopherus agassizii*) are sensitive species that do or used to occur in the valley.

Figure 37. Moapa Crawling Water bug, *Limnocoris moapensis* (Hemiptera: Naucoridae) endemic to the Moapa Warm Springs complex in southern Nevada, USA. Photo credits: L.E. Stevens.

Conservation

In accord with its mission, the US Fish and Wildlife Service manages and maintains WSNWR and has conducted several major rehabilitation efforts to protect the complex assemblage of endemic and endangered fish and aquatic invertebrates there. First, the resort was dismantled and the swimming pools removed. Although native to oases in southern California [209], by 2000 non-native *Washingtonia fillifera* fan palms strongly dominated the site, to the extent that the springbrooks emerging from the Plummer and Peterson Warm Springs complexes flowed only over palm root crowns, not reaching the ground. Furthermore, non-native tilapia, other predatory fish, and mosquito fish were ascending Muddy River and threatening native fish and aquatic invertebrate populations. The US Fish and Wildlife Service engaged a team of us to inventory springs, remove most of the palm trees, and construct gabion fish barriers to exclude non-native fish from the spring outlets. They also established nature trails and an exceptional outdoor stream-tank aquarium viewing area where the visiting public can see the native fish and endemic spring snails in their natural habitat. Thus, this inland MCZ site has become an exceptional example of biodiversity conservation though improved springs management.

3.3.16. Chile: Mainland MCZ

Geography

Central Chile's Mediterranean climate landscape is tectonically, biogeographically, and culturally extraordinary. It occurs in a long thin strip of land that extends from sea level discontinuously over the Central Coastal Mountains and into the Chilean Central Valley, and up to 6893 m at the top of Mt. Ojos de Salado at 27°S along the crest of the Andes. The MCZ in Chile occupies more than 100,000 ha, approximately 35% of the country. The northern extent of the MCZ lies in Chile's District 5 (Valparaiso Region) just south of La Serena at a latitude of approximately 32°S. It extends south to District 8 (Bíobío

Region) near Concepción, at about 38°S along the coast. The MCZ extends into Chile's Central Valley, and farther inland to the south and into Argentina. Annual mean precipitation is highly variable, ranging from 300 to 800 mm/yr, decreasing by nearly 40% from the coast to the Central Valley. Maximum temperatures reach 35 °C in December and January. As of 2023, the population of the MCZ was approximately 14 million people, 75% of Chile's total population of 18.5 million [210]. Of that total, nearly 12% of the total Chilean population was indigenous, primarily Mapucheans.

Geology

With the uplift of the Andes beginning in mid-Mesozoic time as South America separated from the rest of Gondwanaland, the geology and geomorphology of this western coastal MCZ has been the result of tectonic interactions, most recently between the Pacific Nazca Plate, the South American Plate, and the Antarctic Plate. The Nazca Plate is subducting under the South American Plate in the Peru-Chile Trench, which reaches a maximum depth of 8065 m and has a movement rate of nearly 9 cm/year. A northward forcing of the Nazca Plate is occurring at its boundary with the Antarctic Plate, with the Chilean Triple Junction expressed at the Taitao Peninsula on the southernmost end of the MCZ. Consequently, the Chilean MCZ is a topographically complex landscape with much recent and active volcanism and frequent seismic activity. This landscape configuration produces many relatively short, steep rivers, which are commonly baseflow sourced at lower elevations by geothermal and coldwater springs.

Three relatively large rivers flow through the Chilean MCZ. The 380 km long Biobío River is the second longest river in Chile, and it reaches the Pacific Ocean at Concepcíon in the Biobío Region (VIII). Terme Avellno is a streamside hot spring in the middle reach of the river that has been encircled in concrete to provide recreational access during different mainstream flow stages. The 240 km long Rio Maule reaches the sea at Constitucíon in the Maule Region; and the 250 km long Rio Maipo flows through Santiago. All of these rivers head in the Andes, but are fed by many geothermal and cold water springs, some of which have considerable value to indigenous cultures and to the recreation industry.

While terrestrial geology (particularly that of the northern mining districts (e.g., [211]) has been intensively studied, the exploration of the mineral deposits associated with seafloor vent springs ("black smokers") or in diffuse sedimentary deposits (e.g., on the floor of the Antarctic-Nazca plate boundary) are in their infancy [212]. Such seafloor vent spring mineral deposits are attracting the attention of the mining industry and may initiate future socio-cultural changes along the Chilean coast.

History

Multiple indigenous cultures occupied the MCZ in pre-historic times, including the Mapuche, Picunche, and Cunco peoples, with a peripheral presence of the Chiquiyane, Pehuenche, Puelche, and Aonikenk cultures. However, most of the indigenous population in the MCZ was, and remains the Mapuche Culture, with lesser populations of Ayamara and Diaguita cultures. The Inca occupied northern Chile, including the northern portion of the MCZ down to the Maule River from the 15th and early 16th centuries, just prior to the arrival of the Spanish. With the conquest of the Incan empire through genocide and European diseases, Spanish rule was initiated in Chile. The 2023 CIA World Factbook [210] summarizes subsequent Chilean history: "The Captaincy General of Chile was founded by the Spanish in 1541, lasting until Chile declared its independence in 1810. The subsequent struggle became tied to other South American independence conflicts, with a decisive victory over the Spanish not being achieved until 1818. In the War of the Pacific (1879–83), Chile defeated Peru and Bolivia to win its current northernmost regions. By the 1880s, the Chilean central government cemented its control over the central and southern regions inhabited by Mapuche Indigenous peoples [restricting them to small reservations, as their lands were sold off for exploitation]. Between 1891 and 1973, a series of elected governments succeeded each other until the three-year-old Marxist government of

Salvador Allende was overthrown in 1973 by a military coup led by General Augusto Pinochet, who ruled until a democratically elected president was inaugurated in 1990. Economic reforms, maintained consistently since the 1980s, contributed to steady growth, reduced poverty rates by over half, and helped secure the country's commitment to democratic and representative government".

Vegetation and Ethnobotany

The vegetation of the Chilean MCZ has been studied with considerable intensity compared to the extraordinarily similar Californian MCZ vegetation, as well as other regions with a Mediterranean climate (e.g., [47]). The Chilean MCZ lies at the southern border of the Neotropical Region in the Chilean Winter Rainfall-Valdivian Forests Region [213]. The coastal areas are vegetated by matorral: sclerophyllous, evergreen shrub, and sub-arborescent tree vascular plant species, with some succulents. Endemic species in this habitat include the followign: *Adesmia bedwellii* and *Austrocactus spiniflorus*; high elevation *Chaetanthera flabellifolia* and *C. incana*; and Cactaceae *Eriosyce armata*, *E. coimasensis*, *E. eriosyzoides*, *E. marksiana*, and *E. senili*s ([214] https://www.rbge.org.uk/, accessed on 9 December 2023). The Chilean matorral differs from California's chapparal by supporting columnar cacti like *Trichocereus chiloensis*, *Puya* bromeliads, and scattered *Jubaea chilensis* palms.

Mooney et al. [215] report that, like California, the Chilean MCZ between latitudes of 30° and 40° supports vegetation along a dry to moist aridity gradient that transitions from semiarid shrublands with succulents, to evergreen shrublands, to a broad-leafed evergreen woodland/forest. In a comparative study of MCZ vegetation patterns on two continents, they note that while the elevational gradient in Chile is progressively depauperate, that of the Californian Mediterranean climate zone increases in species richness. This is likely due to the narrower piedmont area, longer annual dry period, and the restrictions of fog-based precipitation in Chile compared to California (L. Stevens, personal observations). It also may be related to disturbance frequency, as California chapparal is strongly and regularly prone to wildfire, while Chile is less so, except in developed areas like Valpariaso where introduced fire-tolerant Eucalyptus is abundant and contributed to disastrous fires in late summer/autumn 2014 and 2024.

Many plant species in Chile have ethnobotanical and food value. León-Lobos et al. [216] conducted a national review of reported edible plants and their manner of use. They reported that 330 (7.8%) of the nearly 4300 plant species in Chile were used as food, primarily by indigenous cultures. They documented the consumption of fruits, roots, and leaves of 196 genera in 84 families. The most species-rich families were Apiaceae, Asteraceae, Cactaceae, Fabaceae, and Solanaceae, and the most common edible growth forms were perennial herbs, followed by shrubs, trees, and annual or biennial herbs. They also compared their data with other countries, of which that of Spain (another MCZ) demonstrated a similar percent (5.9%) of potentially edible plant species. One species known at MCZ springs such as the Laja complexes (below) is known as *nalca*, pangue, or Chilean rhubarb (*Gunnera tinctoria*). With leaves approaching 2 m in width, it is conspicuous but sometimes difficult to harvest. The long leaf stalks can be cut down and stripped, peeled, and either eaten fresh or boiled and turned into jam.

Chilean Springs and Recreation

Although many aspects of Chile have been well studied, cultural relationships associated with spring ecosystems have received little attention. While many springs are appropriated for domestic and agricultural use, the recreational and balneotherapeutic values and economics of hot springs are among the best known of such relationships. About 20 km east of Antuco in Chile's Biobío Region (VIII), the Manantiales de Laja (North and South; Figure 38) springs produce most of the perennial headwater flow of the Rio Laja. The southern springs emerge at the crossing of the Sendero las Chilcas and the northern springs emerge a few hundred meters to the north, both in Laguna de Laja National Park. One or more recent eruptions of the 2979 m tall Volcan Antuco stratovolcano dammed the

Laja Valley between 1624 and 1869, creating Lago Laja lake. Water from the lake moves beneath the natural basalt flows dam, emerging about 7 km to the southwest in massive gushet springs complexes. The springs are a popular tourist attraction and support abundant madicolous habitat and dense cliff-wall wetland and riparian vegetation, which stand in marked contrast to the sparsely vegetated volcanic adjacent upland landscape. Most of the headwater flow of the river is diverted downstream for agricultural purposes by multiple communities along the river.

Figure 38. South Laja Springs showing multiple gushets emerging from beneath a recent basalt flow from Volcan Antuco (https://www.myguidechile.com/things-to-do/laguna-del-laja-national-park, accessed on 10 January 2024).

Many other hot springs exist throughout the Chilean MCZ; however, we have yet to locate any mapping data and information on the economic value of visitation. One recreational hot spring of note is Termas Geométricas Hot Springs (Figure 39). This complex contains >60 spring-fed pools and waterfalls, with temperatures ranging up to 80 °C. The springs complex was modified over the past two decades into a work of modern structural art designed by architect Germán de Sol (https://www.germandelsol.cl/memtg.htm, accessed on 10 January 2024) to facilitate visitor movement and enjoyment of its many soaking spots through this steep and topographically complex, tectonic landscape.

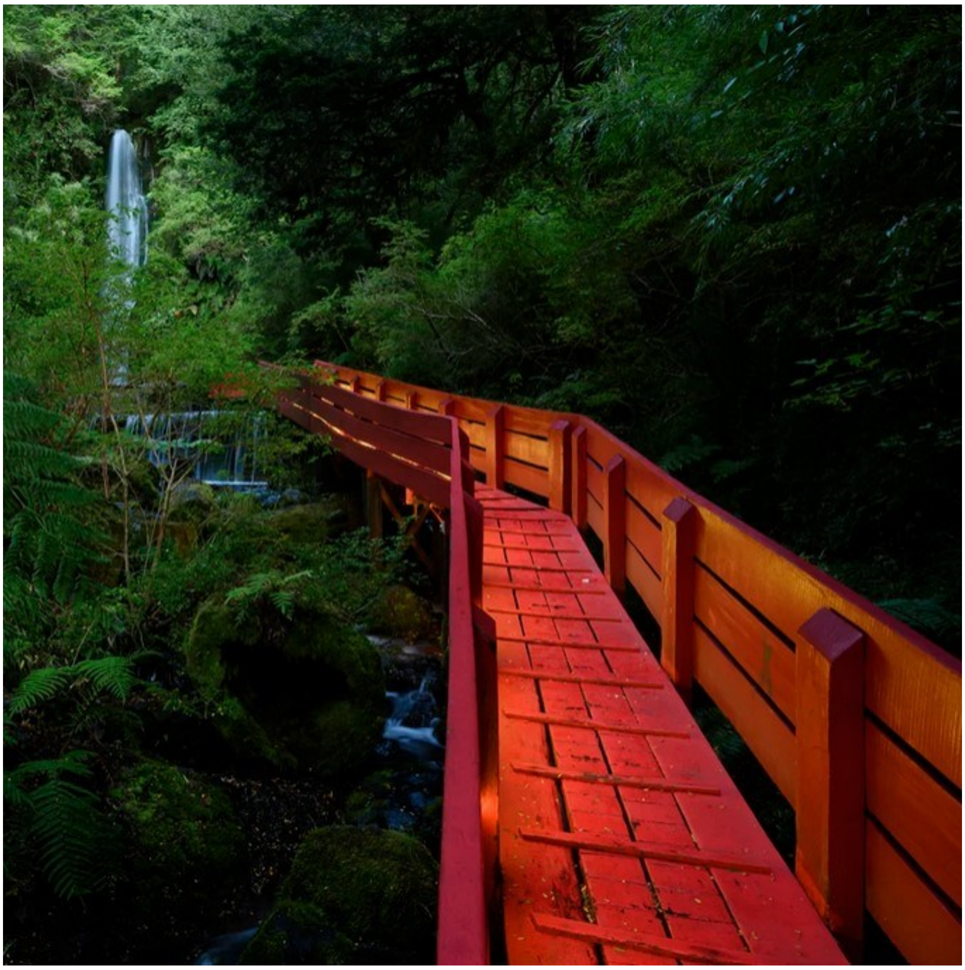


Figure 39. Termas Geométricas Hot Springs Complex consists of 17 pools, three waterfalls and 60 fountains of pure hot water gushing out at an average of 65 ºC over more than 500 m of stream, making it a unique experience. This springs complex was converted by architect Germán de Sol into a work of architecture, allowing visitors to bathe at ease in pools of pure thermal water any day of the year, even when it is cold, raining or snowing in winter, or refresh in natural forest during the heat of summer (photo permission: German del Sol, Architect, Geometric Hot Springs, Chile: https://www.germandelsol.cl/memtg.htm).

Conclusions

Chile lies in a globally recognized biodiversity hotspot, and much of the area of concern lies in the MCZ. Approximately 40% of Chile's vascular flora is endemic [213–217], and a high proportion of its vertebrates have also been reported as threatened [218]. Nonetheless, there appear to be few endemic plant species in Chile that are spring-dependent. This pattern is similar to that noted in California by Stevens [20], although he commented that intact California springs support a disproportionate percentage of rare plant species.

In contrast, many California springs and those in other desert regions support high numbers of endemic invertebrate and fish species (e.g.,[56]). *Phenes raptor* (Odonata: Petaluridae) (Figure 40) is one of only 10 species remaining in this oldest, most ancestral lineage of dragonflies. It is Chile's largest dragonfly and flies over low-order, quickly-flowing streams in at least the southern part of the MCZ (LES, personal observations). Studies of this rare group are few, but in the California Pacific Coast MCZ, its petalurid larvae are reported to live along helocrenic wet meadow edges in vertical burrows, emerging nocturnally to feed on land. LES also observed several large species of stoneflies (Plecoptera) in spring-fed Chilean streams. However, given the generally low level of information on Chile's spring ecosystems, the extent of rare, endemic, or culturally significant biota in those habitats has yet to be determined.

Figure 40. *Phenes raptor* (Odonata: Petaluridae), whose larvae are springs-dependent in helocrenic wet meadows in Chile (photo: L.E. Stevens).

3.3.17. Chile: The Galapagos Island of Floreana

Introduction

Missing from most cultural anthropological studies are the intensity of personal interactions around springs. Since subsistence in MCZ landscapes is often extremely challenging and stressful due to limited water availability and quality, springs are often jealously guarded and the subject of considerable and sometimes violent human conflicts. While few tropical MCZs are recognized, the Galapagos Islands appear to qualify as such. Here we briefly review the history of the island of Floreana as a fairly well-documented example of the intensity of inter-personal and sociological interactions that likely exist around many scarce water resources in MCZs.

Geography and History

The island of Floreana is a 173 km^2, low elevation (maximum 640 m a.s.l.) volcanic island in the southernmost portion of the Galapagos Archipelago. It last erupted in 1813, subjecting the island to a massive wildfire. The only known source of freshwater on the island is a perennial spring that emerges from a basalt hillslope several kilometres from the coast. Wittmer [219] mentions another remote, likely ephemeral spring, but its obscure location remains unknown. She cited evidence of pre-European human presence in Incan stories and ceramic pottery shards found at this spring.

Tomás de Berlanga, the Spanish Bishop of Panama, was the first European to locate the island, but then quickly abandoned it. It may have been his expedition that released domestic livestock and companion animals which subsequently became feral. Subsequent temporary visitors to the islands included buccaneer William Dampier with his British and French comrades, followed by Scandinavian whalers, and the island was the site of American naval conflict with the British during the War of 1812. Ecuador declared the islands as their property in 1834 and started three unsuccessful penal colonies there. A Norwegian fish cannery operation in the 1920s also was unsuccessful. However, all of these early explorers, pirates, and unsuccessful colonists used the Floreana spring as a critical water source.

Satan Came to Eden

The first Europeans to successfully colonize Floreana were the German doctor Karl Ritter and his friend Dore Strauch, who settled there in 1929 in a utopian effort to distance themselves from society [220,221]. Inspired by them, Heinz and Margret Wittmer, with stepson Harry, settled on the island at the perennial spring in 1932, and with much effort were able to successfully farm around that spring ([219] Figure 41). Later in 1932, Austrian "Baroness" Philipson-Wagner de Bousquet and her consort of three men landed on the island and demanded access to the Wittmer's spring. They were reluctantly granted permission to camp there as her group made plans to build "Hacienda Paradiso", a luxury hotel on Floreana's west coast. Over the next two years, the Baroness appears to have shot her servant while trying to shoot another island visitor, as witnessed or alluded to by Wittmer and Strauch. Subsequently, the Baroness and one of her consorts mysteriously disappeared and may have been murdered, perhaps by Ritter and the other remaining consort. However, in trying to escape Floreana by boat, the surviving consort died of thirst on nearby Marchena Island. Dr. Ritter died, or perhaps was murdered, shortly thereafter through food poisoning.

Using the water of the spring, the Wittmers raised their family on the island, which subsequently was subject to American occupation during World War II. After the war, because of their heritage and remote location, they were ridiculously accused of sheltering Adolf Hitler, whom it was rumoured had secretly escaped from Germany to Floreana. Persevering through all the drama and nonsense, the Wittmers persisted, later moving downslope to the coast, where they established a guest house that still serves island visitors. Although a lurid and peculiar cultural history of a remote, quasi-Mediterranean island and its spring, such romantic infatuation, greed, intrigue, violence, and also hard work, compassion and dedication to family and community, as well as other elements of human nature undoubtedly weave through complex sociological fabrics of life at many focal Mediterranean springs throughout the world.

Figure 41. Wittmer Spring, the only permanent water source on Floreana Island in the Galapagos Archipelago. Photo: L.E. Stevens.

4. Overall Results and Discussion

4.1. Integrating the Literature Review with Case Studies

Overview

Our screening of the Web of Science for Mediterranean springs cultural research provided 126 relevant papers (Figure 41A). The years of publication on the references returned from that inquiry ranged from 1994 to 2023. Geographically (Figure 42B), seven papers were found on global Mediterranean areas, and six papers focused specifically on the Mediterranean Basin. Studies in Italy strongly dominated the literature, with 43 references, followed by Greece (21), Türkiye (20), the Iberian Peninsula (8), California (8), South Africa (6), North Africa (5), and Chile (2). No literature was returned in this search from southwestern or southern Australia; however, other references were recovered from more detailed examinations of those landscapes. Organizing the papers by main keywords resulted in 13 categories (Figure 42C), including: "history" (16); "management" (15); 11 each in the categories of "cultural heritage and traditions", "law", and "water supply"; 10 each in the categories of "exploitation and human impacts" and "pollution/contamination"; 7 each in the categories of "agriculture" and "economy"; and 6 each in "religious use" and "energy"; and "balneotherapy" (5). Our WoS search failed to return writings and books that did not contain the key words of the search. For example, WoS did not detect works from ancient history (e.g., Pliny the Elder's ca. 77 A.D. discourse on Mediterranean springs [222]), and relevant recent books like Broad [75] and Robinson [106] in Greece, and Solomon's [2] historical overview of the role of water in cultural evolution, with multiple references to regions with Mediterranean climate. Nonetheless, our literature analysis, coupled with the case studies described above, provides a much-improved understanding of the extent of contemporary scientific progress on this subject, how and where studies are being conducted, and the primary uses, management, traditions, economic and legislative aspects, threats, and issues surrounding cultural interactions with these focal ecosystems (Figure 43). Below we describe the elements and implications of cultural and economic values of springs from the results of our WoS literature review and in the context of the case studies described above.

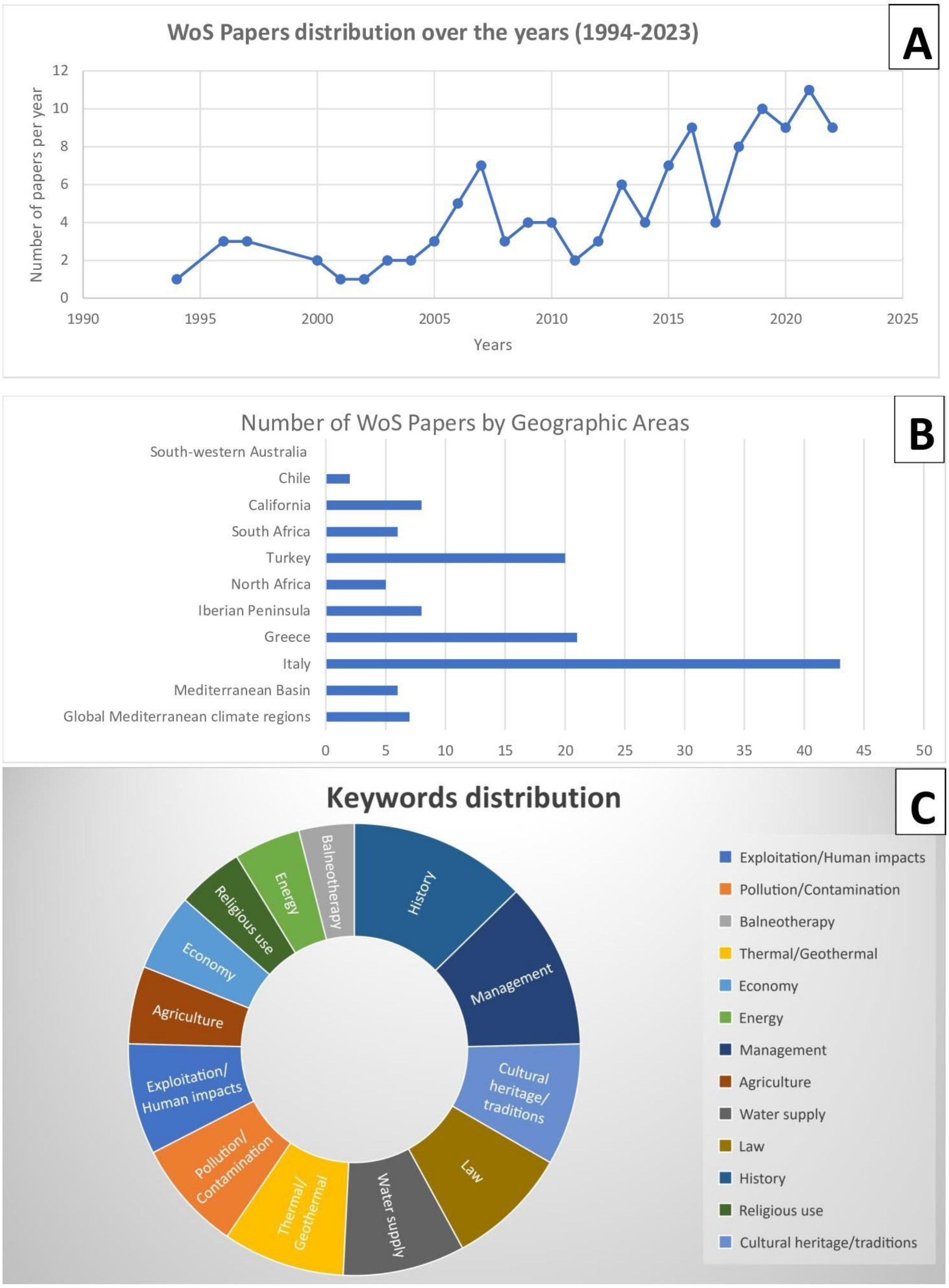


Figure 42. (**A**) Number of studies on cultural aspects of springs in Mediterranean climate published between 1994 and 2023. (**B**) Geographic analysis of cultural research on Mediterranean springs, 1994–2023. (**C**) Frequency of mentions of themes listed in keywords among the 126 references found on socio-cultural studies of springs in Mediterranean climates.

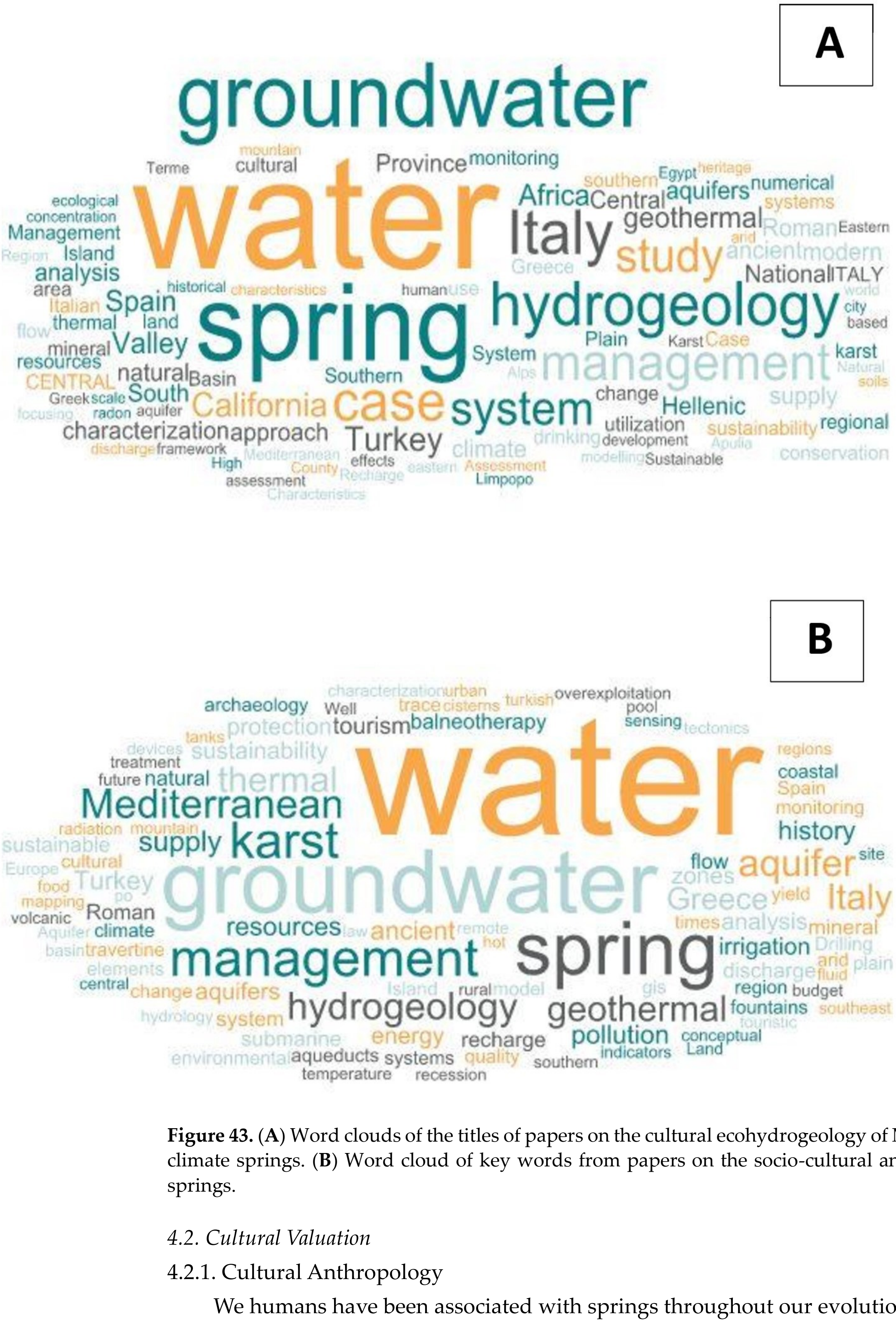


Figure 43. (**A**) Word clouds of the titles of papers on the cultural ecohydrogeology of Mediterranean climate springs. (**B**) Word cloud of key words from papers on the socio-cultural anthropology of springs.

4.2. Cultural Valuation

4.2.1. Cultural Anthropology

We humans have been associated with springs throughout our evolutionary history, and springs have played a pivotal role in human social organization in both ancient and modern civilizations, as described in the case studies above. Our affiliation has involved not only subsistence, rural, or urban water supplies, but also extends to profound relationships and beliefs about aesthetic, divine, magical, sustainable, and healing properties and values of springs. Paleohydrological reconstruction of the Olduvai Gorge in Tanzania revealed early hominin remains at springs 1.7–1.8 Mya [59] and the suggestion that cooking meat may have originated in hot springs, prior to the use of fire [223]. The ancient cities of Corinth (Greece), Rhodes (Aegean Island), Priene (Türkiye), and Syracuse (Sicily) all were founded in relation to karst water supplies [61], as were pre-Roman Apuli settlements in the central-northern Italian region of Puglia, and other communities in karstic areas of the Mediterranean Basin [62]. The establishment of Western Greek Apoikiai (colonies) near springs represented practical and symbolic connections with the landscape, a determinant part of their traditional identity [63].

New advances can arise from studies of these ancient relationships with springs, as demonstrated by recent studies of Roman hydraulic systems [64]. In addition, claims about the uniqueness of the occurrence of rare species in Europe can be clarified. Fonte Aretusa arises on the Mediterranean shoreline in the former Sicilian city of Syracuse. The spring was regarded as the channel through which the demigod Arethusa escaped to the surface from the submarine city of Arcadia, and she was a protectress of Syracuse. Various texts remark that Fonte Aretusa is one of the few European localities for papyrus (*Cyperus papyrus*; the aquatic plant growing in the middle of the spring in Figure 23); however, that species is absent in drawings of the spring in the 18th and 19th centuries [136,138], casting doubt on its nativity or long-term occurrence there. There remains much insight to be gained by studying the history of MCZ springs culture.

In the New World, indigenous cultures still retain strong connections and reverence for springs for health, spiritual well-being, and recreation. For example, Mono Hot Springs in the Sierra Nevada Mountains of California, has a long history of traditional use by the Mono Tribe [224], and Puritama Thermal Spring in the Atacama Desert, Chile has been used by the inhabitants there since pre-Columbian times [225]. Similarly, in Türkiye, fountains are the foundation of much cultural heritage and are still today important for aesthetics and functionality in urban space and public life [65], and as described above].

4.2.2. History

Historic literature confirms the cultural and socio-economic significance of springs and provides insight into ancient lifestyles and behaviours, as evidenced in most of the case studies report above. Archaeological evidence reveals the development of the qanat (excavated tunnels that focus springs water) prior to the Greek Classical period. Minoan hydrologists and engineers created long underground qanats to collect and focus springs flow from bedrock walls and alluvial deposits to supply eastern Crete palaces and settlements with freshwater from 3200–1100 BCE [226]. *Qanat*-aqueduct technology was employed to direct water from Gihon Spring though the Siloam Tunnel into the city of Jerusalem in the early 7th century BCE. Similar conveyances were developed by the Persians in the middle of 1st Millennium BCE, a technology that subsequently spread towards the Arabian Peninsula and Egypt [66]. The construction of the Hadrianic Aqueduct was completed in 140 BCE, providing spring water to Athens residents for the following millennium. Romans constructed advanced aqueducts from 312 BCE—ca. 300 CE to provide large quantities of springs water to urban centres for potable and bathing uses. The Ottoman Empire reintroduced large aqueducts to supply their urban centres with springs water for religious and social needs [64]. For example, the city of Safranbolu, Türkiye is famous for its abundant water resources and pool rooms, which serve as examples of the spatial use of water in traditional residential architecture [67]. From the times of the Pharaohs to the Persian dynasties, and from Greek to Roman periods, the ancient literature is replete with examples of the use and regard springs held for these populations.

4.2.3. Religious Values

As mentioned in Section 3.2.3 (above) religious aspects of springs are significant and common throughout the Mediterranean basin, and likely in all landscapes managed by indigenous cultures. Elements of religion include stories, myths, symbolism, and rituals. The Western world's most famous and culturally influential spring is likely Castalia Spring at Delphi. Although somewhat overshadowed by the masculine influence of the

Temple of Apollo, the prophetic powers of Pythia, the woman of the Delphic Oracle, were pivotal in western geopolitics between the eighth century BCE and the fourth century CE. Delphi (*delphys*, "womb") was regarded as the centre of the earth (*Gaia*). The emission of nitrous oxide and other aromatic hydrocarbons caused the middle-aged female oracle to pass into trance and delirium, through which she issued her often puzzling pronouncements [77,78]. Individual oracles were replaced in the role of Pythia after serving several years, but it is difficult to over-estimate the wealth, power, and influence associated with Castalia Spring, as the aristocracy of the Mediterranean world at that time sought divine advice, bringing with them tribute and constructing statues in her honour.

The practise of baptism, ablution, or ritual cleansing is common to both Abrahamic and Asian cultures, and is philosophically and architecturally inseparably linked to springs [70]. The history of spiritual cleansing ceremonies arises from ancient roots, becoming codified in: the Jewish Tanakh as *tvilah* (immersive ablution); both the Christian Bible's Old Testament (Numbers 19:1–22; Leviticus 14–16:24–28) and the New Testament (e.g., Mark 1:3–4, 9–11; Colossians 2:12) as baptism, the washing away of sins; and the Islamic Quran and *fiqh as wudu* (regular partial/non-immersive ritual washing) and *ghusl* (fully immersive ablution). Eastern religions of Hindu and Buddhism also emphasize the use of clean water for physical washing and metaphorical spiritual cleansing and rebirth into a divine sphere. Thus, ritual cleansing represents spiritual re-creation. "The waters of the cosmic sea, upon which Vishnu dreams into existence Brahma and our universe, represent the shrouded mystery of our origins. At the same time, water's life-sustaining role caused it to become associated with fertility and the mother goddess" [207,227]. Churches, mosques, synagogues, and many temples provide for baptism and/or ritual washing, and hence were typically located sufficiently near springs to provide the necessary clean, clear water. While debates in some religious circles rage over the spiritual legitimacy of partial versus full immersive ablution, our modern daily renewal through baptism or washing in anthropogenic, on-demand geothermal springs (i.e., showers and baths) constitutes a contemporary continuation of these practical and ritual traditions.

4.2.4. Recreation

A wide array of geothermal springs exists in tectonically active MCZ lands throughout the world. Because of their attraction as recreation sites, virtually every country has a list of its hot springs [228]. Here and from the above case studies we list a few of the better-known Mediterranean hot springs. The Waterberg area of Limpopo Province, South Africa has temperatures ranging from 30–52 °C and is used for bottling, domestic, or recreational activities [229]. Mono Hot Springs, in the eastern Sierra Nevada, California, has traditional use by the Mono Tribe and is an inspiration for improved land management [224]. Puritama Thermal Spring, in the Atacama Desert, Chile, is characterized as a place of rest and has been used for recreation since pre-Columbian times [225]. The hot water springs of the natural and cultural Pamukkale Protected Site are in southwest Türkiye in the ancient city of Hierapolis [230]. Terme Alte near Bologna, Italy has the unique thermo-mineral groundwaters [231]. The thermal sulphurous waters of Calabria, Italy, are used for their therapeutic properties [232]. Kremasta and Kokkino Stefani thermal springs emerge in the Aitoloakarnania prefecture in northwest Greece and have a lengthy history of use [233]. There are hundreds of geothermal springs in central Chile's MCZ on the tectonically active west side of the Andes Range. One of the more striking examples emerges in a steep ravine between Pucón and Coñaripe in Villarrica National Park. Termas Geométricas Hot Springs contains >60 spring-fed pools and waterfalls, with temperatures ranging up to 80 °C. The site was modified into a work of modern structural art designed by Germán de Sol to facilitate movement through this topographically complex, tectonic landscape.

4.2.5. Balneotherapy

Mineralized spring waters have long been valued for hydrotherapy and balneotherapy. Therapeutic uses have been recorded in ancient Greece since at least 1000 BCE.

Hippocrates (460–375 BCE), from the Aegean Island of Kos, is considered the father of scientific medicine and hydrotherapy. Subsequent Roman doctors developed and recommended hydrotherapy, and the use of hot baths continued from the early Byzantine through the sixth century AD and to the present. Balneotherapy beneficially affects different parts of our bodies: easing rheumatism, dermal, and multi-systemic afflictions; reducing gynaecological, neurological, and musculoskeletal problems; and improving responses to permanent disabilities. Balneotherapy is also popular today through the spa tourism industry for healthy people seeking relaxation in thermal-mineral springs [66]. Spas and thermal springs such as Kangal Fish Spring in Türkiye are sought for the treatment of diseases, like psoriasis [234]. The Isinuka traditional healing spa in the Eastern Cape Province of South Africa is famous for its pelotherapeutic and balneotherapeutic clay-rich soils and natural spring water [235]. Therapeutically acclaimed thermal sulphurous waters include the hot springs in Calabria, Italy, as well as the aforementioned Kremasta and Kokkino Stefani springs in north-western Greece [232,233]. Balneotherapy may also have a curative effect on osteoarthritis through a combination of mechanical, thermal and chemical traits, but the mechanism of action remains unclear [236].

4.2.6. Law

The legislative aspects of springs stewardship arise through the recognition and needs of the public, scientific community, and local to global governance. Collective action is usually needed to create and enforce the practical and legal protection of discharge, water quality, and biological and cultural resources (e.g., [221]). Many examples exist of attempts to legally manage springs, such as the case study of Moapa Warm springs (above) and management of Crystal Springs Dam on the San Francisco Peninsula, California, USA. There, the protection of groundwater resources demonstrates the importance of the implementation of regulatory directives for water supply protection [237]. The current European water legislation, in particular that addressed groundwater protection for human consumption (EU Water Framework Directive, WFD-2000/60/EC), provides objectives and directs actions to properly protect and manage water resources [238]. The implementation of this directive in southern Italy, with its Mediterranean climate and hydrology, is still far behind schedule [239], but in Central Italy the Rieti Land Reclamation Authority directs the management of surface waters for irrigation, as well as for environmental and hydrogeological protection [240]. Although some of these efforts are promising, it is abundantly evident that far more thoughtful, far-sighted, and effective federal to international governmental attention is needed to protect groundwater supplies and the spring ecosystems and cultural amenities they support.

4.2.7. Energy

Springs, and particularly geothermal energy is an inexpensive and sustainable energy resource (described in the California case study above), with a minimal emission of greenhouse gases as compared to fossil fuel use. Geothermal generation of electricity is now occurring in many Mediterranean nations. The first experiments with geothermal energy use began by piping hot groundwater into houses for heating, and using geothermal steam for the production of electricity [241]. But, as in all matters related to groundwater and springs, management is needed to preserve this resource. For example, in Türkiye, which is rich in energy resources, conflicts are arising among competing states over access to geothermal energy sources [242]. In South Africa, subsurface underground pumped hydroelectric energy storage (UPHES) involves the process of the storage of heated water from an overlying karst aquifer for subsequent geothermal hydroelectric energy production. Developed for gold mining operations in the Far West Rand gold field, and with generation capacities of 0.5 to 1.5 GW/plant, UPHESs may also be useful for closing the national grid's peak load shortfall and for the storage of surplus energy from the country's rapidly growing renewable energy sector [243]. Hamma Spring in northeast Algeria is a natural hot spring with temperatures ranging from 80.7–126.6 °C and is similarly appropriated and stored in a thermal reservoir [244]. In Italy, the geothermal energy system of Ischia Island ensures electrical power generation, with important interactions between geothermal exploitation and thermal spring activities [245]. In Spain, since 1970 hydrogeothermal energy has been generated using hot water from boreholes and small generation facilities, especially located on the Mediterranean coast and near Madrid [246]. Thus, although on a global basis the geothermal exploitation of springs has been highly successful, there has been little discussion of ways to preserve hot spring ecosystems, and it is increasingly difficult to study the ecology of unmanipulated thermal springs.

4.2.8. Pollution/Contamination

As results of anthropogenic activities or natural processes, springs are also affected by pollution or different types of contaminants. For example, perchloroethylene (PCE) and nitrate contamination has been examined in the rural area located north of Italian Parma City. There, present PCE concentrations are only slightly higher than the limit set by law, but excessive nitrate concentrations detected in some domestic wells and fontanili represent high risks for both human health and aquatic ecosystems [247]. In central-southern Italy, a recent case of microbial contamination was detected in compartmentalized carbonate aquifers [248]. Two cases of groundwater radon pollution were recently reported in Italy, one in north-eastern Sicily in wells and natural springs at 70 different sites in the crystalline area. The radon levels measured were similar to those reported in southern Calabria. However, additional study is needed to define the role of tectonism on radon contamination in groundwater [249]. DiCarlo et al. [250] reported another case of radon contamination in self-bottled mineral spring waters in 33 mineral spring waters of Lazio, central Italy. Similarly, in Türkiye several years ago some bottled waters were found to contain unacceptably high concentrations of elements, such as sodium, chloride, sulphide, fluoride, polycyclic aromatic hydrocarbons, and several heavy metals. The Turkish government has established legislation regulating allowable limits for such minerals in bottled waters [251]. Major sources of anthropogenically contaminated groundwater in Türkiye include agricultural pesticides and fertilizers, mining wastes, industrial wastes, and pollution from poorly constructed wells, as well as substantial threat posed by pesticides and fertilizers [252]. Turkey is far from alone in facing such dire threats to it groundwater supplies and springs.

4.2.9. Socio-Economics

Human populations are generally tightly clustered in MCZs, with the exception of the eastern portion of the Pacific Coast MCZ in the USA, in southern Australia, and in the Galapagos Islands (Figure 1). Most of the case studies emphasized the impact of growing populations on groundwater availability and quality and, in the case of South Africa, how severe drought radically focused attention on the need for improved planning and management. However, the political and economic stability needed for the implementation of such plans varies widely among nations. The northern half of the Mediterranean basin, North America, Chile, and Australia generally enjoy far greater average wealth than do populations on the south side of the Mediterranean Basin or the land-locked landscapes in east Africa and the eastern Himalaya region (Figure 1). Wealthier populations in many landscapes have generally moved away from subsistent reliance on springs and are generally the beneficiaries of economic globalization. In contrast, many in the poorer landscapes are still wholly reliant on subsistence lifeways and/or are victims of economic globalization. These differences in population distribution and personal wealth exert significant impacts on social and political stability, as well as concern and care for the environment among the various MCZs.

Springs are globally the focus of enormous socio-economic activity, providing a plethora of ecosystem services for human populations in Mediterranean climates. Geothermal springs are focal destination points for tourism and often provide enormous and sustainable rural and nature-based income. The global value of hot springs resorts was expected to reach $77.1 billion in 2022, with an annual growth rate of 6.5% [253], and many examples of Mediterranean hot spring resorts exist. For example, the volcanic hot springs in MCZ Greece, Türkiye, and the Italian southern island of Ischia in the Campi Flegrei area are all important economic resources. The latter has tourism as its primary industry because of its famous thermal springs [254]. While groundwater is essential for economic growth in southern Spain, the main aquifers in the Costa del Sol region there have been depleted by intensive groundwater extraction, leading to the water table drawdown and the loss of springs and hot spring resort tourism [255]. Improving groundwater management and sustaining spring ecosystems can provide long-term economic as well as ecological benefits. In California, Chile, Greece, and Türkiye, substantial recreational economic advantages can accrue with improved groundwater and springs management [256–258].

From these results, it is apparent that cultural and economic trade-offs exist with regard to the management of springs and the groundwater systems that support them (Figure 44). Cultural values (Cv) (Figure 43a) include a wide array of elements supporting both use and non-use natural, biodiversity, aesthetic, recreational, balneological, cultural, and spiritual values that contribute to contemporary and long-term future ecosystem sustainability. Economic values (Ev) (Figure 43b) involve both positive benefits and negative costs, the former often with short-term, non-sustainable gains and the latter the consequences of the former. When Ev ~ or >Cv (economic values begin to approach or exceed cultural values), the springs habitat, associated resources, and cultural values are likely to be sacrificed and degrade, perhaps irrevocably if the spring is fully dewatered.

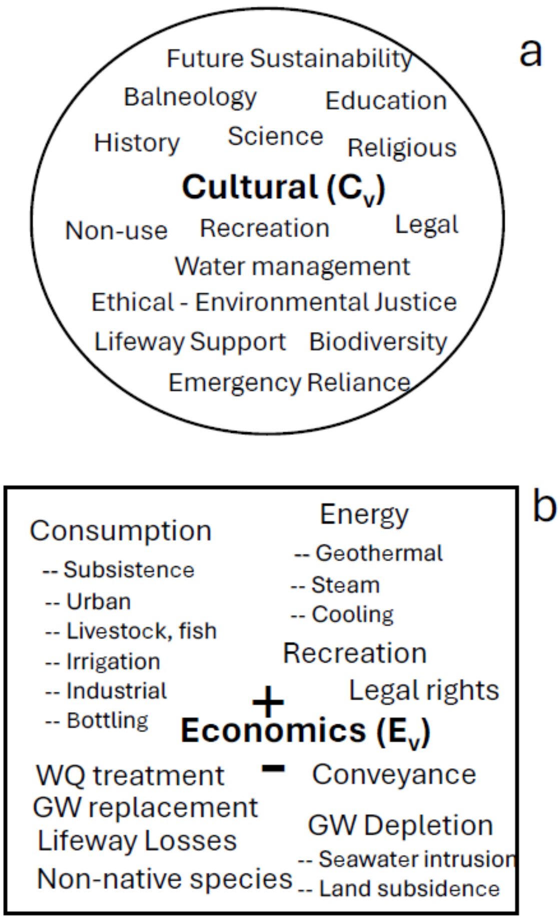


Figure 44. (**a**) Cultural values (Cv) commonly associated with springs, few of which are associated with negative costs. (**b**) Economic values and trade-offs (Ev) associated with springs exploitation:

values above are economically advantageous at least in short-term contexts, while lower variables are costs associated with water management.

4.2.10. Management

Overview: Springs are complex, natural, and often fragile ecosystems that are commonly appropriated for ecosystem goods and services, and the literature contains innumerable examples of such impacts (e.g.,[259]). The dolomitic aquifer in Far West Rand gold reefs southwest of Johannesburg, South Africa, is being dewatered by deep gold mining operations, causing the springs there to dry up [260]. There has long been extensive exploitation of groundwater by well drilling in Türkiye [261], where excessive well water withdrawal and unlimited consumption and insufficient aquifer recharge have resulted in reduced groundwater reserves [262]. The North African springs of Southern Tunisia are also overexploited through steadily increasing groundwater abstraction for industrial, agricultural, and domestic purposes [261]. Problems in water resources management and the overexploitation of groundwater also afflict the East Basin of Thessaly, with a decline of the groundwater table reaching nearly 2 m/year over the past two decades [263]. Thus, case after case of short-sighted groundwater management can be cited everywhere in the world's MCZ landscapes, with little demonstration of long-term vision, planning, or governance.

Despite the many instances of short-sighted groundwater management, some historical and modern examples provide hope. For example, groundwater supplies are primary resources issues in springs management, with diverse applications to human needs. Since ancient times, springs have been among the most heavily appropriated water resources. Sophisticated urban water supply systems have been used in Greece since the Bronze Age (ca. 3200–1100 BCE). For example, in Crete ca. 3200–2100 BCE, early Minoan engineers and hydrologists developed advanced hydraulic structures and technologies for water purification, creating the basis for advanced hygienic technological progress for the following centuries [264]. The city of Cartagena on the southeastern Iberian Peninsula has a rich heritage of water infrastructure and culture of water use. In the past few years much investment has been made to increase awareness of the need for sustainable management of water supplies, and the recycling of wastewater for other uses [265]. In Italy, drinking water sources like springs are now protected through a tri-level safeguarding system: an absolute safety zone is mandated surrounding the source, a zone of respect related to groundwater residence time is also established, and a general protection zone is also recognized [266]. Throughout the Mediterranean Basin karst aquifer groundwaters are recognized as vital and often non-renewable natural resources. In Greece, carbonate aquifers are among the most important sources of high-quality water, which is essential for the country's economy, development, and many anthropogenic activities [267]. In the southeastern Türkiye city of Sanliurfamany, structures have been built since ancient times to ensure adequate water supplies, such as cisterns, baths, aqueducts and dams, water balance facilities, *maksems*, bridges, wells, fountains, and *karliks* [268]. Thus, in ancient and modern times, some practices have conserved groundwater and springs.

Stewardship and Conservation: Many studies have indicated how to improve the management of MCZ groundwater supplies and springs. First, inventory is essential to understand what natural and cultural resources are supported by the aquifer and springs. An assessment of available information is needed to ensure that management planning and actions are appropriate. Following management actions, monitoring is essential to understand the impacts and success of intended and unintended consequences. This simple formula of inventory, assessment, planning, action, monitoring, and feedback has proven effective in many spring, stream, river, and lake adaptive management efforts, across local to regional to national spatial and temporal scales. It is critically important to obtain, document, and archive available data when planning infrastructure projects, as was done in the urban structure of Alexandria and the wider region [269]. It is necessary to preserve and manage groundwater resources in mountain MCZ areas to maintain adequate water supplies for domestic uses, touristic activities, farming, industrial activities, and energy production downslope. Growing demand for water and electrical power in the face of climate changes remains a significant challenge [270]. The only protected spring type mentioned in the EU Habitat Directive is Limestone-Precipitating Springs (LPS) [271], a status largely unrecognised by the public and administrators, and this important spring type remains threatened by water diversion and nutrient enrichment. For example, 36 coastal sites in the North-West Iberian Peninsula have tufa-forming hard water springs classified as priority natural habitats of community interest in Annex I of Community Directive 92/43/EEC as Natura 2000 habitat type 7220* Petrifying springs with tufa formation. Despite this recognition, detailed inventory, enhanced protection, and rehabilitation planning and implementation have yet to be undertaken. Similarly, California has only just begun to try to protect groundwater supplies through its 2014 Sustainable Groundwater Management Act, but its effectiveness has been called into question. Comprehensive local to international programs to promote improved balance between resource appropriation and the maintenance of the ecological integrity of aquifers and the springs they support will improve the sustainability of MCZ groundwater, biodiversity, culture, and socioeconomics. But achieving such ends requires advancing education, outreach, science, and communications with the public, scientific, and governance communities [11,272].

In an effort to quantify the distribution and conservation status of the springs of Mount Tamalpais in Marin County, California involved an analysis of ecological indicators of spring ecological integrity, and Kurzweil et al. [273] identified potentially important springs. They initiated a specific monitoring and conservation program by using standardized field inventory protocols and assembling historical data. That program allowed land and resource managers to learn about, monitor, and evaluate ecological values of springs. In another example, the evaluation of active recharge was identified as key to identifying priority protection measures for sustainable land use planning and groundwater management in the area of the karst aquifer feeding Pertuso Spring, in Central Italy, related to many economic activities [274]. In South Africa, water management is now based on three key principles: sustainability, equity, and efficiency. Not a water-rich country, correct and environmentally just management of water is essential for South African social stability and growth [274]. Other examples of the value of well-planned springs assessment in planning and conservation include Cantonati and Ortler [275], the rehabilitation of Evans Spring (https://caltrout.org/projects/evans-spring-flow-restoration-to-little-shasta-river, accessed on 10 January 2024), East Sweet Springs (https://www.morrocoastaudubon.org/p/sweet-springs-east-expansion.html, accessed on 10 January 2024), and Furnace Creek Springs in Death Valley [276].

Improving the stewardship of groundwater aquifers and springs in MCZs and elsewhere in the world is critically important [11,237,277]. If the aquifer sourcing the spring is relatively intact (not polluted, not dewatered), springs are relatively easily and inexpensively rehabilitated, and can re-develop ecological integrity relatively quickly. Riparian and stream rehabilitation is a major industry in the USA, and has repeatedly been shown to improve the ecological interactivity of the springs or stream system (e.g., [278]). Several simple rehabilitation practices can be undertaken [279]. Fencing the spring outlet protects it from livestock and wildlife damage, but it is important to ensure that water remains available either downstream or to an off-site watering tank for those animals. If a spring emerges on a hillslope and water infrastructure is located at the source, constructing a steppingstone trail to the source will limit hillslope erosion and degradation of the springbrook. Installing escapement structures on tanks will prevent needless drowning of birds and small wildlife attempting to reach water. Lastly, fixing or removing dysfunctional infrastructure will help ensure that water is being used intentionally, or will be allowed to flow at the spring area. While simple and inexpensive measures, such actions can have enormously positive effects on native species and the association of the spring to the adjacent upland landscape. We hope increasing interest and awareness in the ecological well-being of springs for nature and humans will increase support for such actions throughout global MCZs.

5. Conclusions

Mediterranean springs provide essential ecosystem goods and services that sustain the integrity of adjacent upland ecosystems, as well as socio-cultural development and practices [12,20]. The small size of most spring ecosystems causes them to be overlooked in many scientific and resource management analyses, but belies their high degree of ecological complexity, ecosystem individuality, collective heterogeneity, and cultural significance [275,280]. Spatial isolation, coupled with springs' historical significance, sometimes highly elevated productivity, and unique water quality influences opportunities for anthropogenic use and impacts [259]. We suggest that isolation, water quality, persistence, and biogeography shape spring ecosystem structure and function, while climate, water quality, size, and productivity influence cultural appropriation and, reciprocally, cultural evolution. Collectively, these physical, ecological, and socio-cultural interactions help explain both the high levels of biodiversity and endemism at Mediterranean springs, and the intensity of human use and development [56,281,282].

These characteristics and factors have long influenced human cultural occupation, uses of, and beliefs about springs. Evidence for these influences are abundantly demonstrated by the abundance of the paleontological use of springs for ambushing Pleistocene prey (e.g., [283]), archaeological artefacts and iconography (e.g., [106,284]), reference to divine spirits residing in springs (e.g., [285,286]), and the diverse contemporary uses of water at Mediterranean springs described in the case studies, and at all springs around the occupied continents of the world. However, as important sources of freshwater for humans, pristine springs are now rare in most Mediterranean landscapes due to the intensity of long-term anthropogenic exploitation, but those springs that remain in good ecological condition can serve as essential natural laboratories for a better understanding of socio-ecosystem ecology and sustainability practices.

Dramatic discharge reduction in small-flow Mediterranean springs was documented (e.g., [12]), who also highlighted that it is imperative to prioritize the conservation of Mediterranean springs and develop specific management plans for these ecosystems. This review, with its emphasis on cultural values, underlines the cultural valuation of spring ecosystems in MCZs, also fostering new ways to achieve this goal, as a mitigation strategy of the detrimental effects of climate change.

Given the context of this review, it is fair to ask if springs affect culture differentially in MCZs as compared to other climate regions. Cultural development in relation to springs varies broadly across the gradients of freshwater availability and societal circumstances. Humans living in hyper-arid regions may be more severely affected by water limitation, and hence, can be expected to develop stronger beliefs, practices, and policies regarding the valuation and use of limiting water resources. Some populations living in MCZs, while constrained by water limitations, may have more options and flexibility in valuation and decisions about use and policies. In part, greater flexibility in MCZs may also be related to proximity to the sea and more ready access to trading culture. However, access to freshwater clearly remains a limiting resource for Mediterranean communities, and therefore, will continue to be a crucial filter in cultural development. Hopefully, their greater flexibility, creativity, and awareness of globalization and environmental justice will help Mediterranean populations adapt to, and cope with, the worsening crises in freshwater management that face humanity under a changing climate.

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