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Water Stress and Imperial Politics in the Southern Zagros Mountains: An Interdisciplinary Approach in Long-Term Perspective

Andrea Ricci, Silvia Balatti, Elodie Brisset,
Morteza Djamali, Abdolmajid Naderi Beni,
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Abstract

This paper aims to investigate episodes of water stress and the human response to them in the Southern Zagros Mountains from a long-term perspective. The integrative analysis of data from different archives allows for identification of phases of drought in the region, especially starting from the Sasanian period onwards. This investigation also shows that specific imperial politics such as that of the Sasanian Kings Kawād I and Kōsrow I helped to ensure that agricultural communities and practices were sufficiently resilient to these changes. These politics were essentially based on tax reliefs for in-need farmers and state investments on the micro-level. However, pastoral and multi-resources lifestyles remained the ultimate resilience strategies in case of severe aridification.

Keywords: water; resilience; Zagros; interdisciplinary; Sasanian Empire

چکیده

هدف مقاله حاضر بررسی رویدادهای وابسته به تنش آب و عکس‌العمل انسان نسبت به آن در جنوب کوه‌های زاگرس در یک بازه زمانی طولانی است. تحلیل تلفیقی داده‌های به‌دست‌آمده از آرشیوهای مختلف امکان شناسایی دوره‌های خشکسالی در منطقه را که به ویژه از عهد ساسانی آغاز شده فراهم می‌آورد. این بررسی همچنین نشان می‌دهد که سیاست‌های معین شاهنشاهی، مانند اقدامات قباد اول و خسرو انوشروان، توانست به قدر کفایت به تاب‌آوری جوامع کشاورز و روال کشاورزی در مقابل چنان تغییراتی یاری برساند. این سیاست‌ها اساساً مبتنی بر تخفیف‌های مالیاتی برای کشاورزان نیازمند و سرمایه‌گذاری دولت در سطوح خرد بود. با این حال، طرز زندگی شیبانی و چندمنبعی کماکان برترین تدابیر تاب‌آوری در شرایط خشکسالی سخت است.

کلید واژگان

آب، تاب‌آوری، زاگرس، میان‌رشته‌ای، شاهنشاهی ساسانیان.

Introduction. Human use of water resources through the lens of 'resilience'

Human communities are constantly exposed to situations of stress and crisis. These can be related, for example, to natural disasters, climate or ecological changes, demographic pressure and diseases, economic changes, or the development and impact of political institutions. Stress and crisis can lead to societal decline and collapse (Costanza, Graumlich, and Steffen 2007). However, individuals, communities, and societies have often proven to be resilient to such societal, cultural or environmental threats, finding new ways to cope with these challenges (Guttman-Bond 2019; Yoffee 2019).

The procurement, distribution, and consumption of water are crucial necessities for establishing and supporting human life. Increased water extraction and use by humans can have a major impact on the human-environmental system. For example, when too much water is used in relation to the amount of rainfall and underground water supply, this can lead to depletion of water resources and consequently to aridification and drought. Human communities might expand water systems in response to a decrease in the availability of water, due for example to unstable rainfall regime or changes of climatic conditions. This can lead to a combined spiral effect. In dry environments, in particular, minor changes in the amount of water available might generate increased pressure on the stability of the human-environmental system (Jeppesen *et al.* 2015).

Construction and management of hydraulic systems requires control and coordination of the necessary workforce and engineering (e.g., Hodge 2000; Bagg 2004; Rost, Hamdani, and George 2011; Semsar Yazdi and Labbaf Khaneiki 2016). Water supply systems can vary from major irrigation systems dug and constructed under a central authority to small local structures, though the relationship between dimensions and amount of power implemented is not always linear. Water systems need control and constant maintenance, including, for example, cleaning the conduits and canals and dredging the dam. Coordination of the working force is required to organize maintenance (Tamburrino 2010). The procurement and control of hydraulic resources might also lead to social friction and competition. At a political-administrative level, the control of the water system at time of change can also experience pressure, which might lead to renegotiating power structures and socio-political transformations. Changes in human-environmental entanglements due to variations in the water supply may also trigger mobility, migration and even conflict (Scarborough 2003).

In regions of southwestern Asia located beyond the temperate rain-fed zone, techniques to supply and divert water from and to specific locations have been developed as early as the sixth millennium BCE and since

then have impacted the formation of cultural landscapes (Wilkinson 2003, chapt. 5; Wilkinson *et al.* 2012). During the first millennium BCE, water management systems were established in zones beyond the primary riverine civilizations (De Schacht *et al.* 2012; Chambrade *et al.* 2020). The Parthian and Sasanian Empires invested heavily in large irrigation schemes alongside military infrastructures in order to protect crops and control the movement of people and trade (Lawrence and Wilkinson 2017). The building of large water supply systems would have required a detailed understanding of the local water supply, including soil type, topography and climate. Increased implementation of water management technologies transformed previously rain-fed areas in productive agricultural landscape, which could sustain larger population (Wilkinson and Rayne 2010).

The investigation of changes in human-water relationships has the potential to elucidate factors beyond dynamics of changes and transformations. A long-term diachronic perspective enables analysis of the multitude of factors that operate across different levels of threat and how past societies reacted to them and whether a resilient response resulted. This paper aims to investigate hydrological changes and episodes of water stress, and the human response to them in the Southern Zagros Mountains from a long-term perspective.

Methods and main sources of data

Sediments deposited in active lakes of the Southern Zagros provide multi-millennial long archives of the local hydrological conditions. Coupling sedimentological (i.e. texture description, grain-size measurements, microscopic observation of impregnated sediments, X-Ray diffraction) and geochemical analyses (X-Ray Fluorescence) makes it possible to distinguish the alternation in sediment components at a millimetric-scale along the sediment profile. Together with recently improved chronologies, based on radiocarbon ages measured on identified organic terrestrial material, the lake archives of the Zagros can provide a continuous centennial-scale recording of the fluctuations in riverborne sediment supply, occurrence of major floods, as well as highlighting average evaporative conditions of the lake water. Taken together, these archives and studies enable identification of the occurrence of major drought events. Furthermore, the analysis of historical and remote sensing data can provide information on the human influence on the regional hydrology. The available literary sources consist mainly of geographical and historical accounts written in Greek, Arabic, Syriac, and Persian languages and date from the late fourth century BCE to the eleventh century CE. They provide scattered information about the availability of water resources in the Southern Zagros Mountains,

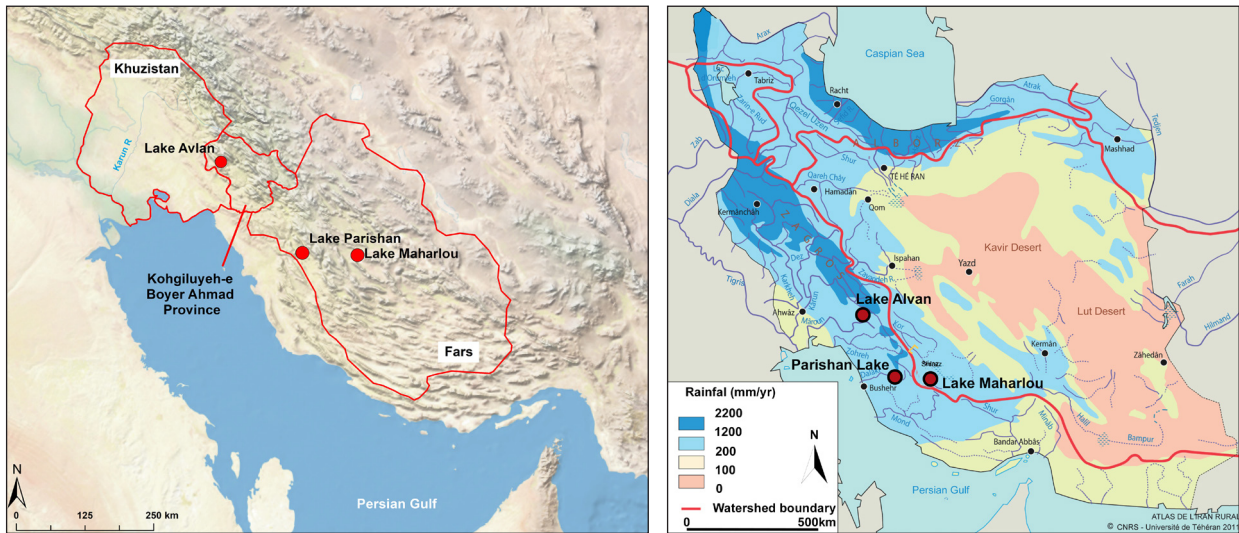


Fig. 1: Left: overview map of Southwestern Iran. The red dots indicate the location of the paleoenvironmental case studies mentioned in the text. Right: Localization of the paleoenvironmental case studies (red dots) depicted over the spatial repartition of the annual precipitations in Iran. Left: by Andrea Ricci, base map by Naturealearth, right: by Andrea Ricci, after Atlas de l'Iran Rural.

events or phases of drought and episodes of governmental responses to them. This information drawn from different historical periods and backgrounds has been identified and interpreted by following the method of historical source criticism.

Combining an analysis of hydrology, stress on water resources, and imperial politics in the Southern Zagros from this perspective allows for identification of phases of aridity and drought in the region especially starting from the Late Sasanian period onwards. The integrative analysis of data from different archives shows that pastoral and multi-resources lifestyles played a central role in contributing to resilience in the face of severe aridification.

Southwestern Iran

Southwestern Iran played a central role in human development in prehistoric and historic times. In the region, three major turning points in humankind's cultural and technological development led to changes in the nature of settlement and in the use of the landscape: the domestication of plants and animals, beginning approximately 9000 BCE (Riehl, Zeidi, and Conard 2013; Zeder and Hesse 2000); the development of the first complex forms of social and economic organization, which led to the emergence of the first urban societies in the plains of Susiana (and lower Mesopotamia) and high plains of the Iranian Plateau from approximately 4000 BCE onwards (Moghaddam 2012); and the creation and consolidation of supra-regional empires from around 600 BCE onwards (Wiesehöfer 2013).

The region of Southwestern Iran stretches from an elevation between approximately 500 to above 3500m a.s.l. In the region, parallel anticlines of the Zagros Range, frequently with exposed steep slope gradients, and intermediate larger or smaller valleys compose a highly mountainous topography (Fig. 1). Thus, in a limited horizontal distance, very diverse climatic and ecological conditions can be found across the region (Petrie, Djamali, and Jones 2018). The climate varies from the dry and hot lower lands closer to the Persian Gulf, where less than 200mm of rain falls per year, to the wetter, cooler highlands, where more than 300mm of rain falls per year (Djamali *et al.* 2011). Because of their environmental potential, the relatively fertile intermontane plains are a favorable location for stable human settlement and agriculture (e.g., Sumner 2003). The higher grounds, with abundant water resources and healthy grasslands, offer an opportunity for an array of socio-economical activities, including pastoralism, transhumance, and hunting. With strong seasonal variation, constant supply of water can be critical year around. As there is virtually no rainfall in the summer months, pastoral communities move seasonally to guarantee pasture to their herds. Within this contrasting series of environmental conditions across the region, the intra- and inter-community dynamics amongst and between groups living at higher elevation and the inhabitants of lower plains create opportunities for local and inter-regional networks of interactions.

For the intermontane plains of the Southern Zagros region, where water supply systems are necessary for major agricultural undertaking and for sustaining large

human population, approaching the study of the human-water dynamics by applying the concept of resilience as a conceptual framework can provide a better understanding of long-term coping strategies of human communities at time of transformations.

Investigating water stress and imperial politics in the Southern Zagros

The inhabitants of Southwestern Iran recognized the importance of water as source of life early on. Pre-Achaemenid and Achaemenid religious beliefs included the veneration of water sources and flowing streams and the performance of offerings by lakes, rivers, and springs (Balatti 2017, 298–301; Henkelman 2018). In the Achaemenid period (550–330 BCE), water was considered a valuable resource and the supply of water to the population was one of the tasks of the Achaemenid Great King (Briant 1994). The Persian kings legitimized their role and position by securing water reservoirs and increasing food production and prosperity in their country (Wiesehöfer 2021). The subsequent empires and especially the Sasanians (224–651 CE) collected and re-interpreted the legacy of the Achaemenids, which included the religious and ideological meaning attributed to water (Callieri 2006; Hartnell 2014, 204–5). In alignment with their political and religious conceptions, the early Persian empires built innovative and extensive hydraulic systems for irrigation purposes (Boucharlat, Gondet, and De Schacht 2012; Chambrade *et al.* 2020; De Schacht *et al.* 2012). As recent paleoenvironmental studies have confirmed, these technological infrastructures, masterfully administrated, enormously advanced agricultural and arboricultural production in ancient Iran (Djamali *et al.* 2016; Saeidi Ghavi Andam *et al.* 2020).

The development of water management techniques and their improvement, maintenance, or abandonment over the course of time is one relevant example for addressing the question of the resilience of society to climate changes from an interdisciplinary perspective. If, on the one hand, archaeological and historical sources can provide information on water supply infrastructures and politics by the states, on the other hand paleoenvironmental archives and in particular lake sediments show the coevolution of human and ecological factors on the *long durée*. They offer a distinct look at the system trajectories over time because of a continuous recording on the fossil information. The concept of resilience allows researchers to follow the transformation of the intensity of the perturbations over time, as well as to distinguish whether the socio-ecological responses are synchronous, lagged, and if they are reversible or not, within the time frame of investigation. The investigation of core sediments from lakes in southwestern Iran integrated with historical studies helps to answer the following research questions:

How important was the optimization of water management in relation to resource pressure and scarcity? Did political and institutional changes influence the maintenance of water management infrastructures and prevent crisis due to water stress at times of climate change?

Lake Maharlou is a large shallow hypersaline lake (Jahanshahi and Zare 2016; Tajabadi, Zare, and Chitsazan 2018) located at an elevation of 1460 m a.s.l., about 50 km south of Persepolis and 15 km southeast of Shiraz (Fig. 2). The lake is subjected to strong natural seasonal level variations, ranging between 100 km² under 0,5 m-depth, and 275 km² under 3,5-m depth (Dumas and Mietton 2003). Lower levels occur in summer (Fig. 3) in connection with high evaporative conditions and groundwater exploitation (Jahanshahi and Zare 2016) and precipitation about null from May to October (meteorological station of Shiraz, study period 1975 to 2016; Zolghadr-Asli and Behrooz-Koohenjani 2020). In winter and spring, solid and liquid precipitations monthly average rainfall of 67 mm per month from December to April feed the lake basin. This results in a tenfold increase of the average river discharge downstream (maximum streamflow of about 10 m³/s, minimum 0 m³/s), seasonally feeding the Lake Maharlou. Here, the average annual air temperature is of 19°C, varying from monthly average of 7°C in December/January and of 30°C in July/August (Shiraz station; Zolghadr-Asli and Behrooz-Koohenjani 2020).

Former works on a 3.5-meter-long sediment core have allowed researchers to establish the chronological and sedimentological contexts (Brisset *et al.* 2019). The sediment sequence of Lake Maharlou (core MAH-B) has recorded the hydrological evolution of the area over the last 3800 years (Fig. 4). The sediments are composed of millimeter-thick alternations of salt and clay layers, that reflect the variations in the sediment depositional processes. Halite beds occurrence is interpreted as reflecting the almost drying out of the lake Maharlou, while the abundance in clay minerals (track by the potassium, K) reflects the abundance of the sediment supply brought by the Khoshk River.

The results of this study show that the complete drying out of the lake, with salt crust formation (i.e. track by halite bed frequency), was infrequent in the time span from 1800 BCE to 800 CE. This means that in the Middle and Neo-Elamite, Achaemenid, Seleucid, Parthian and Sasanian periods, the conditions were not as arid as during previous and later periods in the history of Southwestern Iran. Similar results were found in geomorphic archives of the Pulvar valley in the close vicinity of Lake Maharlou in the Zagros (Rigot *et al.* 2021) and in the Central Iranian Plateau (Schmidt *et al.* 2011), showing a long-lasting phase of sediment alluviation. This period also corresponds to lower values in oxygen-

Fig. 2: Satellite image of the study area with the modern towns of Shiraz and Marvdasht. Lake Maharlou (1474 m a.s.l.) is located in the semi-arid slopes of the southeast Zagros, 50 km to the south of the ancient Achaemenid capital Persepolis. By Andrea Ricci, base map: Landsat 8, October 25, 2018.

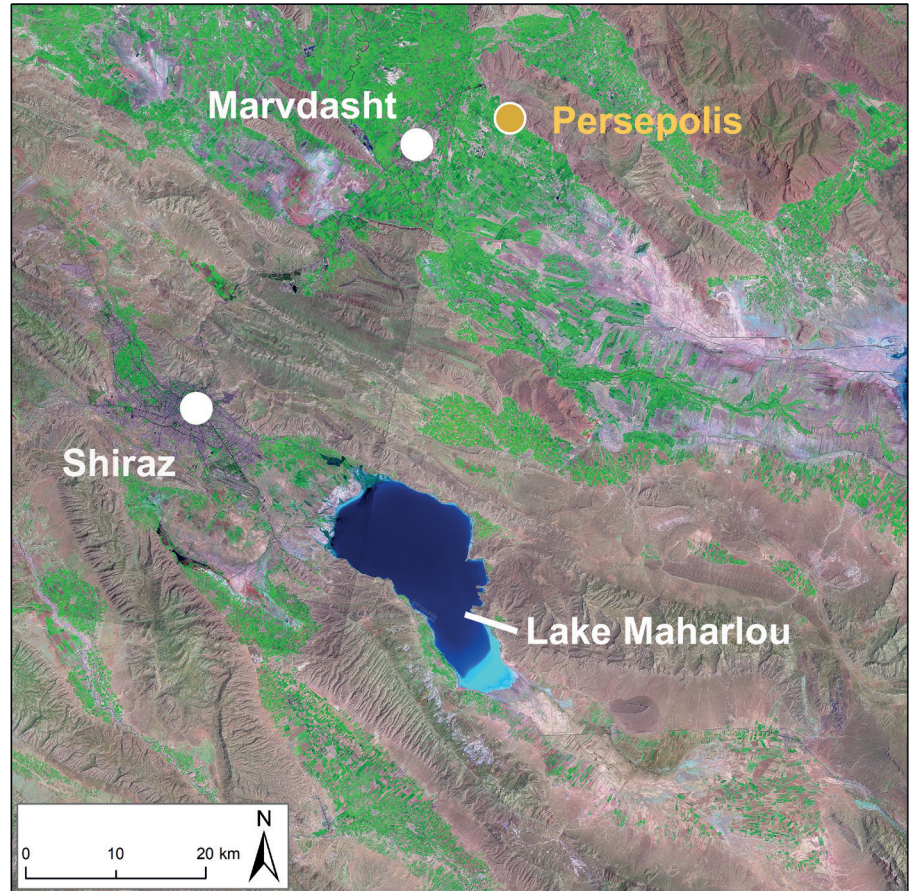


Fig. 3: Lake Maharlou in September 2016 at the peak of the dry season. This saline lake is subjected to strong natural seasonal level variations. © Elodie Brisset.



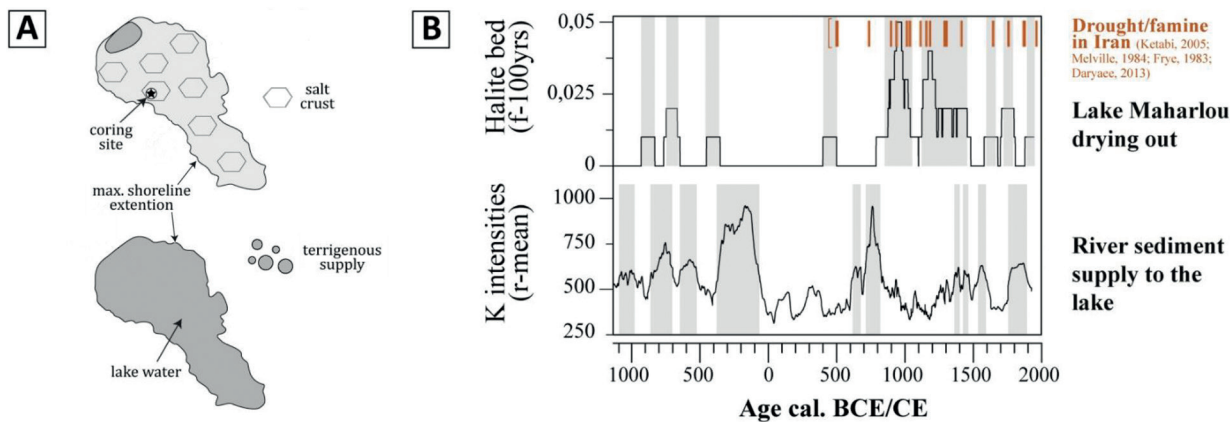


Fig. 4: Hydroclimatic reconstruction over the last 3100 years based on sediments of the Lake Maharlou. Two main situations are depicted (A), tracked by two different proxies (B). Halite bed frequency allows to reconstruct the period of salt crust formation (A), and the K intensities allow to track the change in the sediment supply coming from the river when the lake is filled with water. © Elodie Brisset and Morteza Djamali.

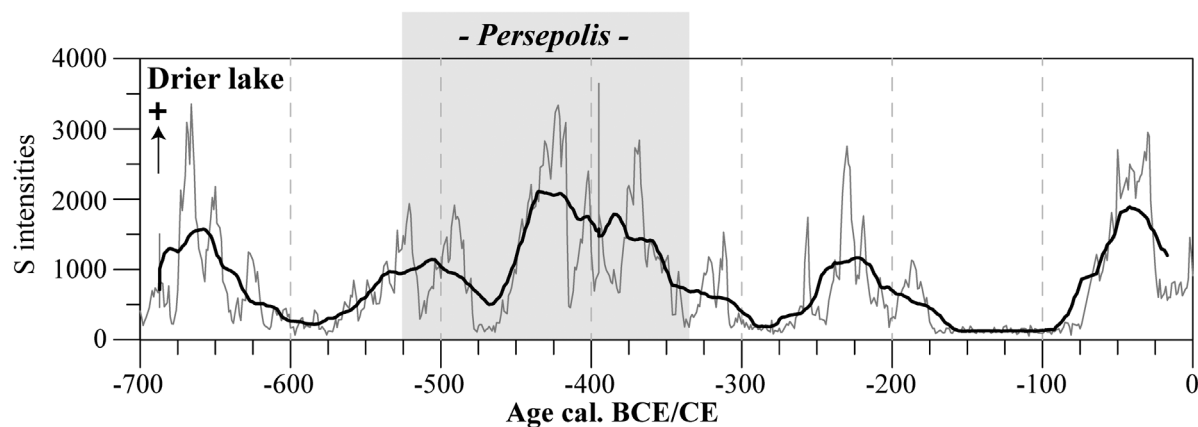


Fig. 5: Hydroclimatic variability as shown by the geochemical analyses of Lake Maharlou sediments in Fars during the period 700–0 BCE. S intensities track the intermediate evaporative conditions of the lake (i.e. gypsum abundance). The thin lines represent a sampling interval of 500 µm, and the thicker ones the running average on 101 data points. The vertical marker (light grey) highlights the span-time of occupation of the Achaemenid capital of Persepolis. © Elodie Brisset and Morteza Djamali.

isotopes records from speleothems of the Northern Zagros (Kuna Ba Cave; Sinha *et al.* 2019) and in Oman (Fleitmann *et al.* 2007), which attest to wetter climatic conditions at that times. Although this was undoubtedly a phase of more humidity, hydrological changes often occurred and are visible in the records. In the Achaemenid period, the river activity was not very intense (transitory low K intensities), thus suggesting increased use of the river's waters. Moreover, a closer look at the dataset shows that gypsum mineral was abundant in Maharlou sediments (track by S intensities) in the time interval 700–0 BCE (Fig. 5). The precipitation of gypsum generally occurs in more intermediate hydrological conditions, when evaporation is very high, and the lake levels are relatively

low. High evaporation was likely favored by an important climate change toward drier regional conditions, that has been dated at 750 BCE in the Zagros Kuna Ba Cave (Sinha *et al.* 2019). We observe an increase in gypsum abundance from 550 cal. BCE, roughly corresponding to the time of the development of the Teispid-Achaemenid Empire. Thus, it is probable that, in a context of a drier climate, increased anthropogenic activities connected to agriculture (irrigation, deforestation, dunging) in the vicinity of the lake caused or amplified the decrease in both fluvial activity and lake volume. These results are comparable with those from Lake Parishan, which is located 100 km to the west of Maharlou. Multiproxy data from Lake Parishan show that anthropogenic activities caused the

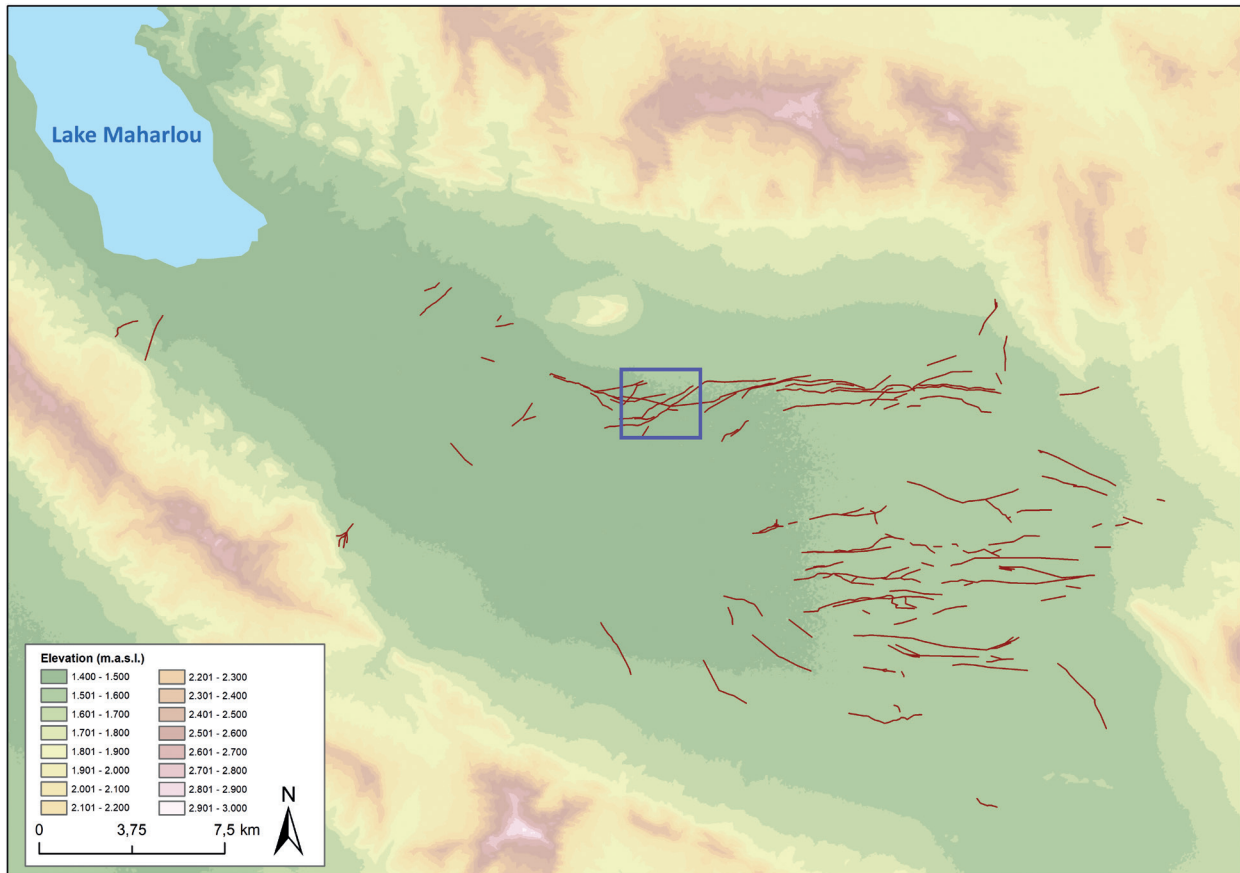


Fig. 6: Lake Maharlou watershed and the location of qanats (red lines) as visible on historical satellite imagery of 1970. The blue rectangle indicates the location of the zoom-in area illustrated in the following figure. By Andrea Ricci, base map: SRTM 1arc.

decrease of fluvial activities and the lake level dropped exactly in the same period (Jones *et al.* 2015). Besides these changes, it appears that the irrigation system and land-use strategy of the Achaemenids did not have significant impact at short temporal-scale on the local hydrological balance. The data at our disposal from Lake Maharlou do not show any consistent pressure on water resources for this historical phase. This result suggests that while water uptake for agricultural and arboricultural purposes increased in the Achaemenid period, the implementation of water management strategies remained sustainable on the long term and did not have a major impact on the availability of the water resources. Written sources praise the large availability of water in Pārsa (modern Fars) until the end of the Achaemenid period. Nearchos, admiral of Alexander III of Macedon, describes the central part of Fars as a region rich in well-irrigated meadows, which had plantations of all kinds and was full of clear rivers and lakes (Arr. Ind. 40. 3-4). Surface water availability also continued in the period that followed Alexander's death, when Diodorus mentions the persistence of cultivated

plantations and natural glades full of trees and streams of water (Diod. 19.21.3).

Multiple factors such as climate change, lower precipitation, increase in the population density, and the construction of additional surface water networks and underground channels in the vicinity of the lake Maharlou in later periods may have contributed to the dramatic contraction of the water body that characterized the phase 800–1500 CE. At Lake Maharlou, the increase in gypsum abundance suggests that drier climatic conditions occurred since the beginning of our common era (Brisset *et al.* 2019). This is relatively consistent with drier conditions observed at Lake Zeribar (Stevens *et al.* 2006) and Lake Neor (Sharifi *et al.* 2015), and might be, at centennial-scale resolution, consistent with several dry excursions as recorded in the speleothems of Kuna Ba Cave (Sinha *et al.* 2019). The fact that only scattered written sources are available and punctual paleoenvironmental and archaeological investigations have been conducted in the Southern Zagros Mountains so far limits the possibility of having an overall picture on these environmental changes

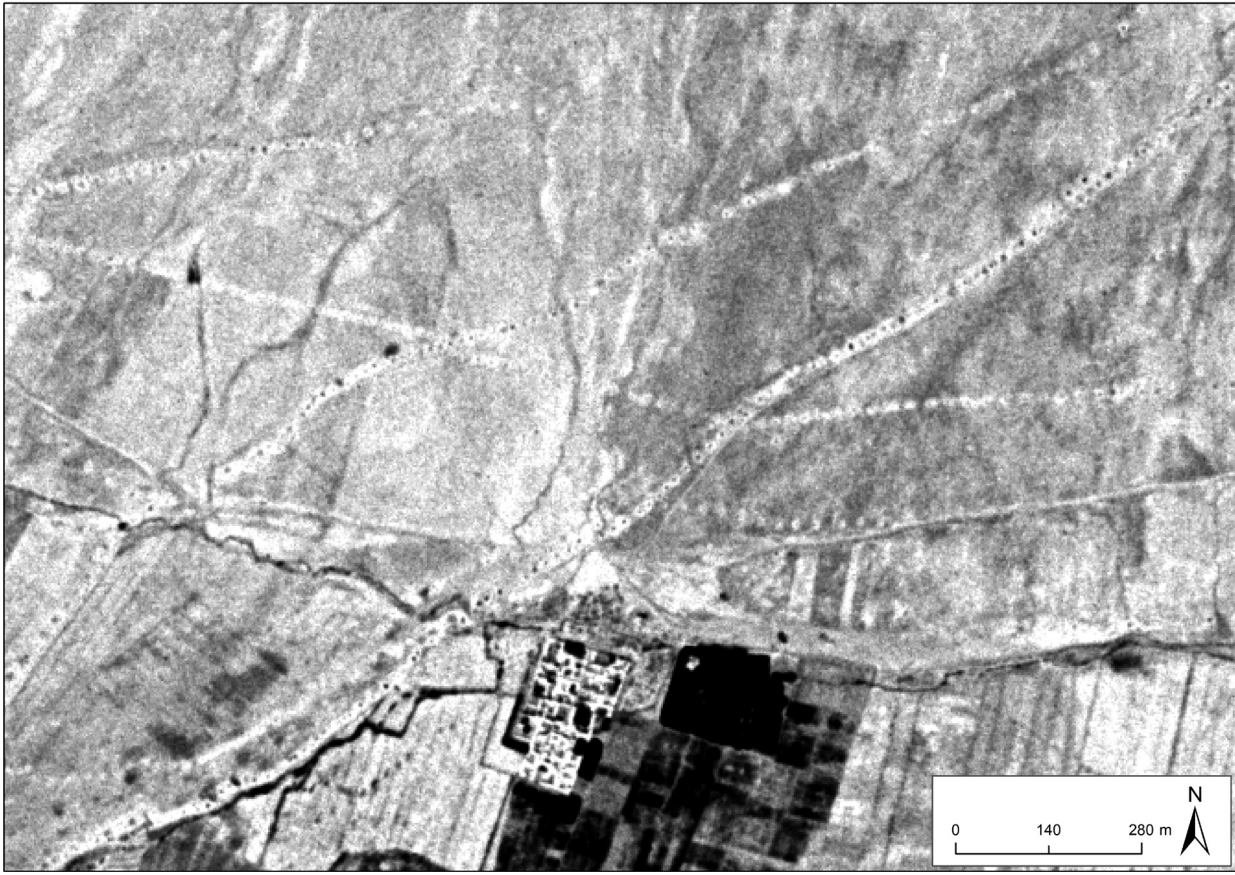


Fig. 7: Example of dense presence of qanats in the Lake Maharlou watershed as visible on historical satellite imagery of 1970. By Andrea Ricci, base map: Corona image DS1110, 24 May 1970.

and human responses to them. While for some periods or regions our data can be compared and combined, for others we have limited or no data. The reconstruction presented here therefore does not aim to be complete and exhaustive, but rather to provide insights into the topic, working hypotheses and future lines of research.

Although there is not much information on Fars in the Arsacid period (c. 250 BCE – 224 CE), recent archaeological studies in other areas of Southwestern Iran show that some of the large water infrastructures commonly attributed to the Sasanians started to be constructed as early as the Arsacid period (Maresca 2019, 208–9). In the Deh-Luran Plain of Khuzestan, for example, old canal and *qanats* systems were expanded and new water-supply networks were constructed under the Arsacids and then more intensely under the Sasanians (Neely 2016). The main economic goal of these infrastructures and related technological innovations was that of increasing agricultural productivity (Maresca 2019, 211). However, this also enormously increased the pressure on water resources. At Lake Maharlou, the large number of *qanats* located in the watershed points to strong disturbances in

the drainage basin in the course of the history of the lake (Fig. 6). *Qanats* are dug in such a way as to allow gravity to direct underground water to the settlements and irrigated areas. Historically, they were dug by hand and maintained by dedicated people who ensured that they were kept flowing. Silty-sandy debris accumulates inside the underground channel, erosion of the channel occurs, ventilation shafts might collapse and obstruct the water flow, and the *qanat* might no longer provide sufficient water unless it is constantly maintained and repaired. *Qanats* provide a sustainable method of procuring water, however, when the groundwater level changes, older *qanats* might become unusable, and new underground water conduits need to be built to tap water at deeper level (Semsar Yazdi and Labbaf Khaneiki 2016).

The increasingly large use of hydraulic works and technology in agriculture allowed the extension of land use and supported larger population in Southwestern Iran especially in the Sasanian period (Neely 2016; Hartnell 2014). However, on the other hand, they also increased pressure on water resources, which, in a context of more frequent droughts, might have been the (co-)

cause of agricultural losses and food insecurity. Written documents record episodes of severe droughts and famine in the Sasanian period (c. 225–651 CE). A well-documented example is that of the drought witnessed in Southwest Asia at the beginning of the reign of the Sasanian King Pērōz (459–484 CE). Arabic, Persian, and Syriac authors note that Pērōz's reign started with a devastating drought, which lasted seven years and also involved Southwestern Iran (Bīrūnī 1879, 215–16). Al-Ṭabarī describes it as follows:

[...] a great famine came over the land for seven years continuously. Streams, *qanāts*, and springs dried up; trees and reed beds became desiccated; the major part of all tillage and thickets of vegetation were reduced to dust in the plains and the mountains of his land alike, bringing about the deaths there of birds and wild beasts; cattle and horses grew so hungry that they could hardly draw any loads; and the water in the Tigris became very sparse. Dearth, hunger, hardship, and various calamities became general for the people of his land (Al-Ṭabarī 1999, 5: 111).

Besides praying to God at the fire temple in Fars to obtain rain (Bīrūnī 1879, 215), the Sasanian King of Kings also adopted temporary measures to face the crisis. Al-Ṭabarī writes that Pērōz suspended taxes, levies (*nā'ibah*) and corvée (*sukhrah*) and that he entrusted the local governments to take all possible measures to sustain the population (Al-Ṭabarī 1999, 5: 110–13; cf. Nahāyat al-Arab 1996, 277–78; Ferdowsi 2007, 7: 16–17; Al-Tha'ālibī 1900, 575–78). The sources seem to agree that the deaths were rare, thus suggesting that the tax relief and the specific measures adopted by the local governments succeeded at least in saving lives. The transfer of authority to the local communities is remarkable since it shows the recognition of the importance of the local subsistence strategies to face episodes of drought and famine. The 'traditional', highly flexible modes of subsistence, which in the mountains of Southwestern Iran also included dry-farming and mobile pastoralism (Potts 2014; Balatti 2017), may have played a key role in the survival of the population in such phases of crisis. It is also reasonable to hypothesize that droughts and famine such as the one mentioned above increased the discontent of the local communities, which lost trust in the figure of the king, since the latter was considered unable to ensure water-supply and prosperity to the country. This criticism and sense of insecurity can be read between the lines of the written sources at our disposal, some openly against Pērōz (Al-Ṭabarī 1999, 5: 111 [in one of the two accounts he relates]; Al-Dīnawarī 1888, 60). Perhaps it is no coincidence that the Mazdakite movement, which invoked the common ownership of the wealth, developed during the reign of Pērōz's son and successor Kawāḍ I (Wiesehöfer 2009; Schindel 2013). Ferdowsi's *Shāhnāma*

offers a fictional, literary account on Mazdak's activities, which probably reflects a memory of some historical facts, including a drought. A passage of "the story of Mazdak" reports as follows:

There came a man named Mazdak, eloquent, leaned and capable. [He was] grand and ambitious. The brave Qubād (Kawāḍ) heeded his words. [This man] rose to become the king's vizier and his treasurer and the guardian of the royal hoard. [Then] a drought caused famine, afflicting both the rich and poor. Clouds disappeared from the sky, and in Iran, none could find any sign of snow or rain. All the people, rich and poor, came to the king's gate, begging for food. Mazdak said to them: His majesty will lead you to the path of hope. (...) When Mazdak heard [this] he kissed the ground and left the royal presence. He went to the royal gate and said to the crowd: Wherever grain is stored, go forth and plunder, making it available to all in the city. Let each man take his share. Those who were starving rushed and pillaged every magazine of grain. [Soon] not a grain of corn was left in the warehouses, be they the citizens', or Qubād's (Ferdowsi 2007, 7:69–72; cf. Al-Tha'ālibī 1900, 596–99).

Social conflicts and economic problems led Kawāḍ I (488–531 CE) and his son Kōsrow I Anušīrwan (531–579 CE), to reform the administration and land-taxation of the Sasanian empire (Gariboldi 2009; Bonner 2011). Assistance mechanisms and financial support for small farmers were instituted to enable the peasants to restart cultivation after, for example, natural disasters (Rubin 1995, 254). This confirms that episodes of drought had become more recurrent, so much that the central government had to directly address and try to prevent the consequences of the problem. Kawāḍ I and Kōsrow I's reforms also favored the rise of groups of provincial, cantonal, and even village bureaucrats such as the *dehqāns*, 'village' magnates who managed affairs, supervised cultivation, and collected taxes on a local level (Tafazzoli 2000, 38–59). These officials became the backbone of the later Sasanian and Early Islamic administration and taxation system. Although the goal and effective success of Kawāḍ I and Kōsrow I's reforms is highly debated, they certainly contributed to the avoidance of over-taxation, supported the local agricultural communities, and thus limited the damage caused by drought and famine. Archaeological case studies show that the system of intensive exploitation of the resources through agriculture and intensive irrigation carried on for a century or longer, only to collapse in the more arid regions of Southern Fars after the Sasanian period (Asadi *et al.* 2013; Hauser, Labisi, and Rashidian, this volume).

Although the archaeological data show that the driest areas of Southern Fars turned to be pastoral lands during

the Early Islamic period, cultivation continued or even increased in other more humid areas or niches with larger water availability. A palynological study on the same core from Lake Maharlou (Saeidi Ghavi Andam *et al.* 2020) indicates that although the arboricultural activities were practiced since the Middle Elamite period with more diversified crop types under the Achaemenids, they did not reach their apogee until the very Late Sasanian and Early Islamic period with a peak in the later Buyid period (tenth to eleventh century CE). The concentration of the agricultural and arboricultural activities in specific, well-watered areas may have contributed to increasing pressure on the water resources of these areas, so much that they became concurrent causes of episodes of complete drying out such as those recorded at Lake Maharlou between 800 and 1500 CE. However, more data from other lacustrine basins of the Southwestern Zagros and in-depth historical research is needed to be able to investigate this phase of remarkable change in the hydrological balance of the lake.

Discussion and conclusion

The analysis performed in this paper shows that the intensive agricultural production and its infrastructures fostered by the imperial systems caused pressure on the environment and water resources of semi-arid regions such as Southwestern Iran. This occurred especially during phases of increased aridity, when long periods of droughts might have led to crop failure. In turn, famine threatened the local agricultural communities, thus exacerbating insecurity and social conflicts. Such a situation could compromise the entire socio-economic system of the region and even of the empire. The example of the Sasanian Kings Pērōz, Kawād I, and Kōsrow I show that the political authorities could intervene with *ad hoc* fiscal and administrative measures in order to prevent and alleviate the consequences of droughts on the local agricultural communities and avoid the abandonment of the fields. Empowering local government officials, who oversaw the administrative and economic management of specific areas within a wider region, probably helped to increase resilience of the system on the local level. It has been suggested that the ruling dynasties had different economic strategies (e.g., crop types) for the adjacent intermountain plains of the Southwestern Zagros which presented different arrays of ecological and climatic characteristics (Djamali *et al.* 2016). Each basin has thus had its own socio-economic history particular to that basin and different from adjacent basins. It follows that the activities of state officials on the micro-level, such as the *dehqāns*, could better safeguard the needs of the local communities in an environment such as that of the Southwestern Zagros Mountains. Our study also illustrates that 'traditional' lifestyles such as mobile pastoralism and dry farming remained resilient strategies for the population in a fragile environment such as that of Southwestern Iran. In case of

severe aridification, lack of state investments or changes in the land-use strategy and economic politics by the state, the local communities might have (re-)adopted more flexible and multi-resource lifestyles to survive periods of stress.

This reconstruction remains fragmentary due to the scattered written sources and the limited environmental and archaeological data available. It is expected that the analysis of sediment cores from additional lacustrine archives located in Southwestern Iran, combined with the study of the historical sources and the archaeological record, will provide insight into human resilience in cases of water stress in the Southern Zagros Mountain region. This includes addressing topics related to climate and hydrological changes and related politics by the states, but also the involvement of the past local communities of the region in strategies of water management (e.g., cooperation in maintaining water infrastructures) and human responses to crises. Along these lines of research, the HighStepLands project will focus on the Kohgiluyeh and Boyer Ahmad Province of Southwestern Iran. Located between Khuzestan and Fars, in the core inner part of the Zagros Mountains, the region is highly mountainous and home of intermontane fertile valleys and plains, which are comparatively smaller than those found in nearby regions (e.g., Fars). The area remains largely a *terra incognita* for archaeological and paleoenvironmental studies. Existing research suggests that the region was home to a complex combination of both pastoral and long-term settlements. The presence of lacustrine archives located at distinct elevations, but in close vicinity to one another, offers ideal conditions for fine-grained paleoenvironmental reconstructions away from the larger plains and larger water basins where previous investigations have concentrated. Considering that the topographic and environmental conditions including the gypsiferous soils offer limited potential for intensive agriculture in the Kohgiluyeh and Boyer Ahmad region, authorities might have applied a different politic of land-use and water management in this mountainous section of the Zagros than in areas where larger fertile intermontane plains are located, as for example in the Lake Maharlou region. The lacustrine archives as well as the archaeological signature might hold record of these different land-use strategies. First investigation of Lake Alvan (Barm-e Alvan) at an elevation of 1018 m, started in November 2020 and the analysis of first two sediment cores are currently underway.

A time-transgressive and multiscale investigation that employs an interdisciplinary approach could lead to the identification and analysis of phases of climatic and socio-economic changes and crisis in the history of the Southern Zagros. Our focus has the potential to detect the anthropic and climatic impact on the environment and hydrology of the region both in densely populated areas and in areas distant from the major urban agglomerates. The long-term approach investigates the fragility of the

human-environment system at different temporal scales and therefore supports an analysis of trends of resilience. This approach enables a better understanding of the socio-cultural-environmental dynamics in respect to phenomena of (re)adaptation and resilience during or after crisis. In addition, the *long durée* view might be the way to fill some gaps and also to create a link between contemporary and past strategies to cope with transformative changes.

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