The Archaeology of Irrigation Technology and Water Management in the Islamic World

Edited by

Timothy Insoll, Rachel MacLean, and Salman Almahari

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Proceedings of the Bahrain Conference, January 2024

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Cover: Excavated *qanat*, Hamad Town, Bahrain

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Foreword

Water has shaped civilizations for millennia, not only as a fundamental necessity but also as a force driving human innovation. Across the Islamic world, intricate irrigation systems and water management structures, such as *qanats*, *aflaj*, aqueducts, and reservoirs, testify to the ingenuity of past societies in harnessing and sustaining what is arguably the most vital resource. Yet, despite their significance, many of these systems remain underexplored and their histories fragmented across time and geography.

The *Archaeology of Irrigation Technology and Water Management in the Islamic World* conference, held at the Bahrain National Theatre from January 7–9, 2024, brought together leading scholars to examine these remarkable achievements. This gathering fostered new insights into the development, adaptation, and legacy of water-related infrastructure across regions from the Middle East and North Africa to Central and South Asia, Sub-Saharan Africa, and parts of Europe.

The way past civilizations managed water reflects skilfulness and adaptability. In environments where water was scarce or unpredictable, they developed sustainable systems that supported entire communities for centuries. As we face modern challenges of water scarcity and climate change, these historical approaches offer valuable lessons in resilience, efficiency, and sustainability, principles that remain as relevant today as they were in the past.

The research presented in these proceedings reflects a wealth of expertise and dedication. I extend my deepest gratitude to the scholars, researchers, and professionals whose contributions have made this publication possible. A special acknowledgment goes to the organizing team, whose commitment and attention to detail ensured the success of this conference and the lasting impact of its discussions. The Bahrain Authority for Culture and Antiquities remains strongly committed to preserving and promoting the rich heritage of water management in our region and beyond.

Shaikh Khalifa Bin Ahmed Al-Khalifa, President, Bahrain Authority for Culture and Antiquities

Chapter 1.
The Archaeology of Irrigation Technology and Water Management in the Islamic World. An Introduction

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Introduction

It is a truism that water is the source of life, or 'the soul of the earth' as the quote usually mis-attributed to the poet W.H. Auden (web reference 1) indicates. It is essential to sustain human life. We are composed of between 60% to 75% water, and if this is reduced by just 4% we become dehydrated, and if by 15%, we die. We can live for a month without food but only a couple of days without water (web reference 2). Thus the provision of water has been a fundamental human concern and remains so, globally. This volume explores human ingenuity in constructing hydrological infrastructure in the Islamic period through examining a series of regionally based case studies that were originally presented in a conference held in Bahrain National Museum in January 2024, convened by the Bahrain Authority for Culture and Antiquities under the Patronage of His Royal Highness Prince Salman bin Hamad Al-Khalifa, the Crown Prince and Prime Minister of Bahrain, that focused upon *The Archaeology of Irrigation Technology and Water Management in the Islamic World*. However, it is not the aim of this brief introduction to summarise the papers which follow, or to attempt to review the existing literature on the archaeology of water and hydrological infrastructure. Instead, it will present a few short introductory remarks to frame the theme of the volume.

Bahrain

The importance of irrigation technology and water management can be seen in the smallest region considered in this volume, the archipelago of the Kingdom of Bahrain, which has a total land area of 786km^2 (web reference 3), excluding recent land reclamation, and which is densely packed with archaeological evidence for hydrological infrastructure, beginning with the pool at Barbar Temple which dates from about 2100 BCE (MacLean and Insoll 2011: 52). Many more sites remain from the Islamic period, and it is likely that some of this infrastructure is in reality pre-Islamic in origin, but this is only a fraction of what once existed. This is best indicated by the almost total disappearance of the underground *qanat* systems and open irrigation canals which once covered the north-central area of the main island of Bahrain, Awal, and were fed from various artesian springs, as Larsen's (1983: 91) map indicates (see Bahrain chapter for illustrations). We discuss these sites in greater detail in our chapter, but it is worth noting that significant effort was invested in their construction which has been revealed through excavation, as in the *qanat* at Hamad Town that was built using bitumen and charcoal as waterproofing material for its base and with a double layer of stone roofing as insulation. Here, it is fortunate that a short stretch of this *qanat* will form the centrepiece of a new park, but it is only in the past few years the realisation has occurred that this evidence of human ingenuity needs preserving, particularly as water has again become a pressing matter in the current climate emergency, as we discuss further below.

The artesian springs that fed the *qanats* have not fared much better with most now dry, and rare examples still containing water are at risk of development, as in Barbar South. An example, albeit dry, that has survived is Ain Abu Zaydan, a very important spring in Bilad al-Qadim, the former Abbasid capital of Bahrain, and its status is reflected in it being referred to by the great Arab geographer Al-Idrisi in the mid-12th century (Insoll 2005). Ain Abu Zaydan also illustrates how rapidly change has occurred as it was in use until the 1970s, latterly for weddings, but is now derelict and neglected though plans are being considered for it to be restored as a heritage site for tourists. This too, is a good indicator of the shift occurring to once more seeing the value of traditional hydrological infrastructure, and within which archaeology has a critical role. Particularly so at Ain Abu Zaydan which seems to also be a site of great age, as indicated by the re-used stone drums, including an upturned sacrificial altar of probable ancient Dilmun age, c.2000 BCE, in the column supporting the roof above, and which implies there was possibly a Dilmun period temple in the vicinity (Insoll 2005: 80-81).

The importance of archaeology is also attested by new discoveries of water-related infrastructure being made, as on al-Sayyah Island, where an offshore freshwater spring was recently discovered and around which traces of a wall were recorded, potentially constructed in the 7th to 8th centuries and protecting a spring potentially used to provide freshwater to ships involved in pearl diving, possibly using a *shādūf* to transfer water between the spring and waiting vessels, and which was a commonly used technology in Bahrain until the 1960s as archival photographs indicate (see chapter on Bahrain). Whilst there also exist many examples of sites which remain un-researched - Adhari, a spring that watered vast palm groves through a canal system, or Ain Buri, or the wells at Hunainiyah near Riffa in the centre of Awal, or the dams at Berak (Pool) Bint Bin Musa that were used to trap water running down wadis from the hills to grow wheat - a precious legacy both of the value of water and human technological expertise in managing this resource, but a legacy which is also ephemeral and needs protection and further investigation.

Lessons from the Past and Addressing Stereotypes and Clichés

But is there a point in preserving and studying the archaeology of irrigation technology and water management? Unsurprisingly, our answer is yes, for though this volume is only focusing on a part of this technology in the sum total of its development and use, i.e. within the Islamic World and then only selectively, this is not inconsequential for we believe that the past does hold lessons for the present and certainly for the climatically more challenging future. The storm that Bahrain experienced in late October 2023 provides such an example for unlike in the past there was no infrastructure to capture and store or manage and drain the rainwater that fell. Instead, it either ran into the sea, was absorbed into the sand, or evaporated, giving a few cooler days and some new plant growth, but nothing tangible, and that precious resource was essentially wasted. Looking to the Bahraini examples we just briefly outlined and consider at greater length in our chapter, we can see that mechanisms can be developed to ameliorate such weather events and in fact realise the opportunities they offer for rainwater harvesting, particularly within the overall sustainable development goals that Bahrain is now implementing (web reference 4), and the (re)development of irrigation technology and water management systems could bring new benefits. Certainly there remain challenges but there are also significant potential advantages, and archaeology provides examples for how this can be achieved.

Furthermore, focusing on the archaeology of irrigation technology and water management in the Islamic World and, more so, spreading awareness of the results achieved, can also help in addressing stereotypes and clichés as, for example, in challenging the etic image that a homogeneous ‘Islamic World’ exists, and one often linked with clichés of hyper-aridity (cf., Mulder 2011 for relevant critique). This is clearly erroneous, as rainfall varies massively within such a vast space stretching, should one wish to impose some sort of boundaries, from the West African Atlantic coast to eastern Indonesia, and where it has been argued that it is uneven precipitation not absence of rainfall that is often the key challenge (Mulder 2011: 648). Hence it can correct the Orientalist notion that interest in water in the Islamic World was a consequence of it being only burning deserts or because it invokes an image of paradise (*ibid.*: 647). Second, it also permits evaluating the origins of this technology and whilst not denying an inheritance from Roman or Sasanian, or even earlier Ancient Egyptian, Mesopotamian, or other predecessors, as in Java, can challenge diffusionary stereotypes, as with the supposed Iranian origins sometimes ascribed *qanat*-type systems (e.g., English 1968: 170), when in reality it now seems that these had independently evolved in various locations wholly unconnected with each other (Charbonnier and Hopper 2018: 7). Equally, the archaeological record of irrigation technology and water management in the Islamic World can highlight how this was not static but subject to development and even revolutionary in how it permitted advances in agriculture (e.g., Watson 1983), settlement, and industry, as with sugar production (e.g., Walker 2003).

Previous Research

Yet it is surprising how little these issues have been examined in archaeological scholarship, for in more general studies Islamic material is either absent (e.g., Chapman Davies 2008), or minimally represented (e.g., Żuchowska 2012). Whilst within Islamic studies most interest in water at the type of ‘global’ level which the conference, and subsequently this volume consider, has been in the field of Art History, but that only comparatively recently, and notable here we would highlight Blair and Bloom’s (2009) edited volume, *Rivers of Paradise: Water in Islamic Art and Culture*. Previously, where water technology was acknowledged in Islamic contexts, this was generally as part of a larger architectural study (e.g. Michell 1978; Hillenbrand 1994) and frequently missing are the comparative data on irrigation and water management – i.e., the typology, forms, and chronology – and it is these which reveal the ingenuity of the forgotten generations who dug the ditches, wells, and tunnels, and built the dams and reservoirs. This data of course exists in the form of archaeological evidence scattered through myriad journals, books and reports, but it is beyond our competence or requirements to attempt to summarise here. This said, we would draw attention to one valuable project, *Source of Life: Water Management in the Premodern Middle East* (web reference 5), two of whose collaborators participated in our Conference (Jaafar Jotheri and Louise Rayne), as research that has engaged with archaeological evidence in a useful way.

The Papers - Emerging Themes

However, the focus of that project is explicitly on the Middle East and in contrast, our conference aimed for a 'global' perspective in exploring the archaeology of irrigation technology and water management which was achieved except for the limitations imposed by the failure to find scholars to speak on certain regions, notably South Asia and Iran. Moreover, two participants were unable to provide contributions for this volume (Tjahjono Prasodjo, Louise Rayne) meaning that Southeast Asia and North Africa have subsequently had to be excluded. Thus the coverage is centred on the Middle East to a larger extent than we would have liked, with three contributions on material from Saudi Arabia (Al-Otibi, Al-Rashid, Weigel *et al.*), and one each on the southern Levant (Lucke), Bahrain (Insoll *et al.*), Egypt (Soliman), Iraq (Jotheri *et al.*), Oman and Yemen (Harrower and Zaribaf), and Turkey (Verhoeven), as well as on Sicily (Castrorao Barba), the Iberian Peninsula (Martín Civantos), the Swahili Coast, encompassing Somalia to northern Mozambique as well as Madagascar (Baumanova), and the Samarkand Oasis in Uzbekistan (Mantellini).

These contributions consider a wide range of material from different perspectives and employ varied methodologies to achieve this, yet it is possible to identify various points that emerge including how:

- Diverse the range of irrigation and water management technology is, and how this still needs detailed consideration in many regions.
- The integration of environmental and geoarchaeological evidence is vital in its archaeological investigation.
- Multiple stakeholders are often involved – from local communities through to a government level.
- For their effective investigation and certainly for their protection and re-activation there is a need for community involvement in the processes of archaeological interpretation and management.
- In some instances possibilities exist to bring these systems back into use but in other contexts this is impossible.
- There exists extensive potential to use the archaeological examples to indicate the fundamental value of water to contemporary communities.
- These archaeological investigations can literally bring water into the open – whereas modern systems render water hidden and thus it becomes taken for granted.
- The archaeology of water equals applied archaeology and as well as generating greater understanding of the importance of water can also raise awareness and interest in archaeology more generally.

Conclusions

In conclusion, we hope that this volume both highlights research completed but simultaneously the possibilities for learning from the past about irrigation technology and water management which, to repeat, are existential issues which we feel it is unwise to ignore not just in the Islamic world, but globally.

Acknowledgements

We would like to thank our Patron, HRH Sheikh Salman bin Hamad Al-Khalifa, the Crown Prince and Prime Minister of Bahrain, and his representative at the conference opening, HRH Sheikh Muhammad bin Salman Al-Khalifa, our sponsors BAPCO and UNESCO, and the Bahrain Authority for Culture and Antiquities, particularly Sheikh Khalifa al-Khalifa, Ms Noora Lori, Ms Melanie Muenzner and Ms Huda Alawi, and Ms Fatima Khamis.

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Chapter 2.
The Archaeology of Water in Bahrain in the Islamic Period

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Introduction

The Bahrain archipelago covers a land area of just 786km², and has a main island, Awal (Bahrain), measuring only 48km by 16km but is, nonetheless, densely packed with archaeology (**Figure 1**). Of this, the Islamic period remains least investigated, and within it the archaeology of irrigation technology and water management has been almost wholly neglected. Instead the archaeological focus, where a distinctive theme can be discerned, has been upon urbanism and settlement patterns, ceramics, international trade, and Islamisation (e.g., Frifelt 2001; Kervran *et al.* 2005; Insoll 2005a; Insoll *et al.* 2016). The aim of this chapter is to begin to redress this through highlighting examples of key 'water' sites of varied types, so as to examine what, if any, research has been completed on them, and to assess how some might be revitalised, interpreted, preserved, and presented, and in so doing evaluate what might be learnt from these sites for water conservation and management in the present, particularly as this is an issue that we contend will become increasingly pressing as the climate emergency intensifies.

Previous Research

There has been no systematic evaluation of the archaeology of Islamic period irrigation technology and water management but incidental references to relevant infrastructure occur in excavation reports. At Barbar Temple (**Figure 1**), for example, a stone-lined and plastered well shaft excavated to a depth of 350cm had been filled with ceramic sherds of 9th-10th century (all dates are CE, unless otherwise specified) date, along with other refuse materials (lithics, faunal remains, fragments of metal and glass) presumably as it fell into disuse or because it was deliberately brought out of use through this action (Frifelt 2001: 13). Similarly, in the Islamic Town (14th-16th centuries) at Qala'at al-Bahrain (**Figure 1**), part of what was interpreted as possibly a hammam (bath house) was excavated (Frifelt 2001: 50, 62) – though this functional interpretation can be questioned on the basis of a lack of evidence, except for the presence of a well. Whilst at the earlier Islamic shore fort at Qala'at al-Bahrain (c.11th to 13th centuries), which has erroneously been ascribed a pre-Islamic Tylos-period origin (c.350), wells and a drain are referred to (Kervran *et al.* 2005: 169, 170, 194, 201) but otherwise no mention is made of water supply within this sizeable structural complex. In other instances, water supply is wholly ignored, as in the report on the excavations of part of the settlement (12th/13th to 18th centuries) at Barbar South (cf. Salles et al 1983) (**Figure 1**), which appear never to have been published, though nearby there is a substantial well that we consider further below.

Reference has, however, been made by various observers to the many kilometres of disused *qanats* in Bahrain over the years. Bibby, for example describes *qanats* encountered during his surveys with Glob in the early 1950s, 'They extend for miles, running from the lower slopes of the central hills of Bahrain to the lowlands of the west coast...But the qanats no longer carry water' (Bibby 1970: 51). By this date the water level in the springs and wells which fed the *qanats* had dropped too low to be used *(ibid*: 52). Bibby and Glob collected ceramics from around these springs 'and promised ourselves that one day we would come back and do more' (ibid: 53), though this never happened. Similarly, James Belgrave (1973: 94-95) referred to the *qanats*, describing many as still is use, but others having fallen into ruin, and also how according to local tradition they were used by the people of Bahrain to move through to attack the rear of the Caliph's forces sent against them in the eighth century, but whether this is correct is unknown. While more recently, Ward describes seeing a *qanat* system still in use at al-Markh village (**Figure 1**) just south of the Budaiya Highway running from Ain Aliwah well, although pumps were needed to raise the water to the level of the channels (Ward 1993: 155-157).

However, the most important previous research on the archaeology of irrigation systems was by Curtis Larsen (1983). Although completed only 40 years ago, the change since has been massive and the extent of cultivated land has declined substantially. This is

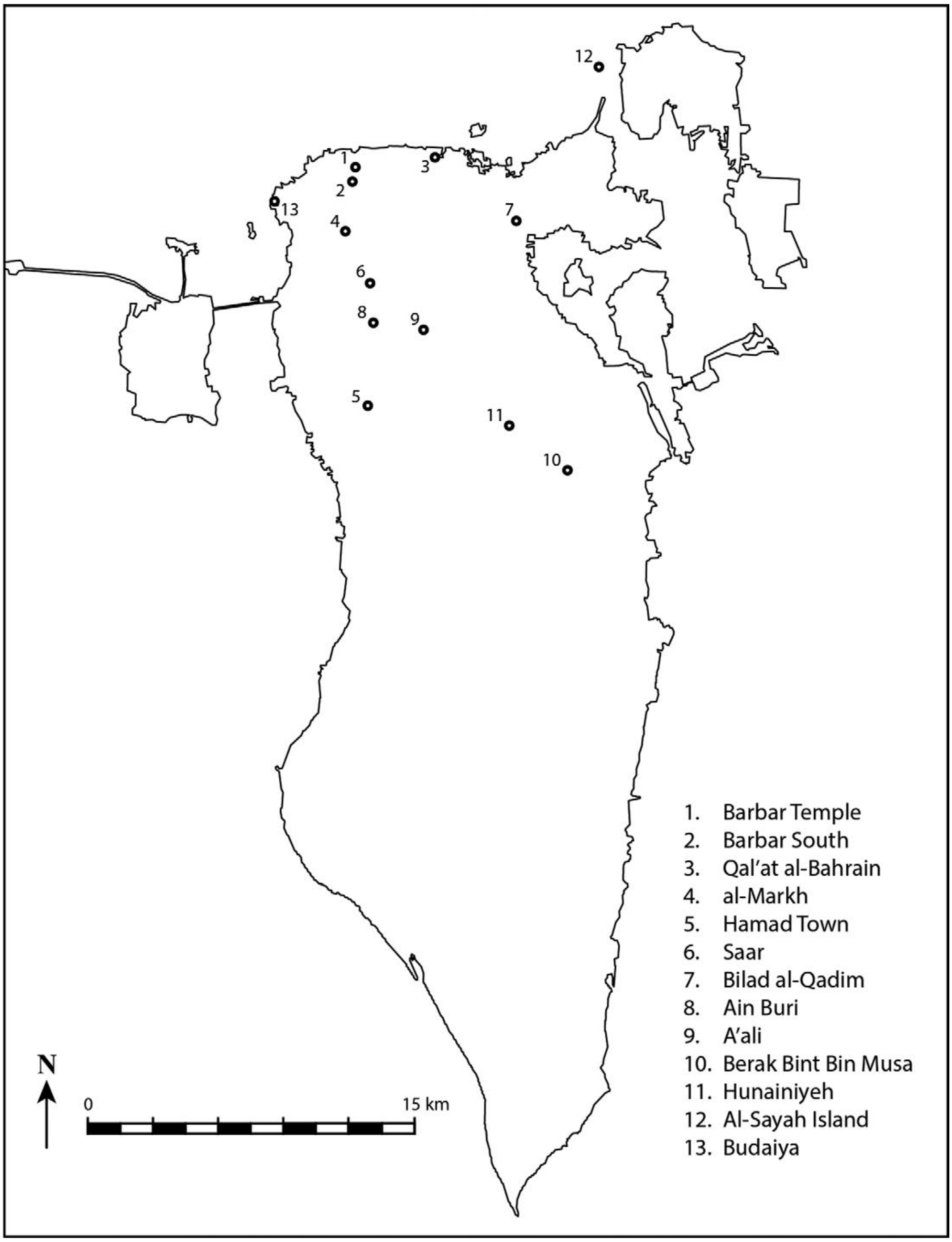

Figure 1. Main site locations in Bahrain.

clearly apparent in Bilād al-Qadīm, the former Abbasid period capital, where aerial photographs indicate its rapid urbanisation and loss of agricultural land (**Figure 2**). This also means that the associated irrigation systems are destroyed or buried under new structures, as we discuss below. Conversely the land reclaimed from the sea, which is continually increasing the size of Bahrain, is sterile and although modern sewage and water supply systems are laid to facilitate new housing and other building development, drainage is frequently insufficient, and water storage and irrigation infrastructure non-existent.

Hence a key result of Larsen's (1983) research is the reconstructed map of irrigation systems he provides (**Figure 3**). Although largely undated it does attest how the communities on the north and west coast of Awal made extensive use of irrigation for date gardens and vegetable plots. The systems illustrated could also combine *qanats* dug under colluvial soils with open

Figure 2. Urban growth in Bilad al-Qadim. 1. 1959. 2. 1977 (photos. BACA).

irrigation canals, and these were all fed by artesian spring water from the east Arabian aquifer, using water of significant age, as he notes that this aquifer was charged by Late Pleistocene rainfall in central Arabia and possibly subsequently in the 'Neolithic wet phase' but that major volumes of water had not been added in the last 6000 years (Larsen 1983: 133). Thus this precious resource was rapidly being depleted as illustrated by Larsen's (*ibid.*: 137-138) modelling of spring levels based on settlement chronology with the oldest (Barbar) settlements at the highest elevation (12m above sea level) and these progressively dropping in altitude (to 2m above sea level) as they decreased in age, and which was directly related to the decline in spring levels. However, what Larsen did not do in any detail was investigate the *qanat* technology itself, instead focusing on broader 'geoarchaeological' narratives meaning that little was known about the construction of these irrigation systems until recently.

Hamad Town *Qanat*

The first excavation of a *qanat* system in Bahrain, at Hamad Town (**Figure 1**), took place in 2022 and was completed in 2024 and the results give insight into how these were constructed. Although now dry it had been fed by the Um Jrai spring, one of the locations referred to by Lorimer (1908: 231; **Table 3**) which was once walled, and the remains of standing stone walls were uncovered along the northern, eastern, and northwestern edges of the central depression containing the spring (**Figure 4**). Larsen's (1983: 192) explanation of why these types of walls were constructed appears feasible - either to stop sand dune encroachment or to prevent lateral water loss through absorption into the surrounding soils - and we believe both factors might apply at Um Jrai. Parts of the bank sloping down to the spring below the walls had also been coated with lime plaster which gave way to a stone revetment lower down the bank suggesting these were further mechanisms adopted to avoid water loss.

The remains of a building were found immediately west of the enclosure wall. This was associated with the irrigation system but was of unknown function and had been remodelled over time with a second later wall running northwest to southeast built directly upon wind-blown sand with no traces of foundations. The remains of a sequence of floors were found in the northern section of the building, two of which were made of white plaster, and suggesting that the building had been in use over some time. This is important in providing correlation for the period of time the *qanat* was in use and the ceramics from sieved contexts in the building were of late Islamic (18^{th}-20^{th} century) date and included both diagnostic Pale Grey Gritty Ware and A'ali Common Ware (Tait 2025: 18).

The *qanat* channel mouth led from the south-west section of the spring and although the original end to the channel was presumed to be missing it was found that the channel curved round to the north-east as it entered the well. In total, the surviving section of *qanat* was 480 m and bisected by a modern road. Accordingly, it was labelled the north and south fields, and as the northern section was much better preserved this was the main focus of excavation. It was also noted that the *qanat* was not straight but curved slightly at various points which we suggest was a deliberate design feature to deal with the force of water travelling down

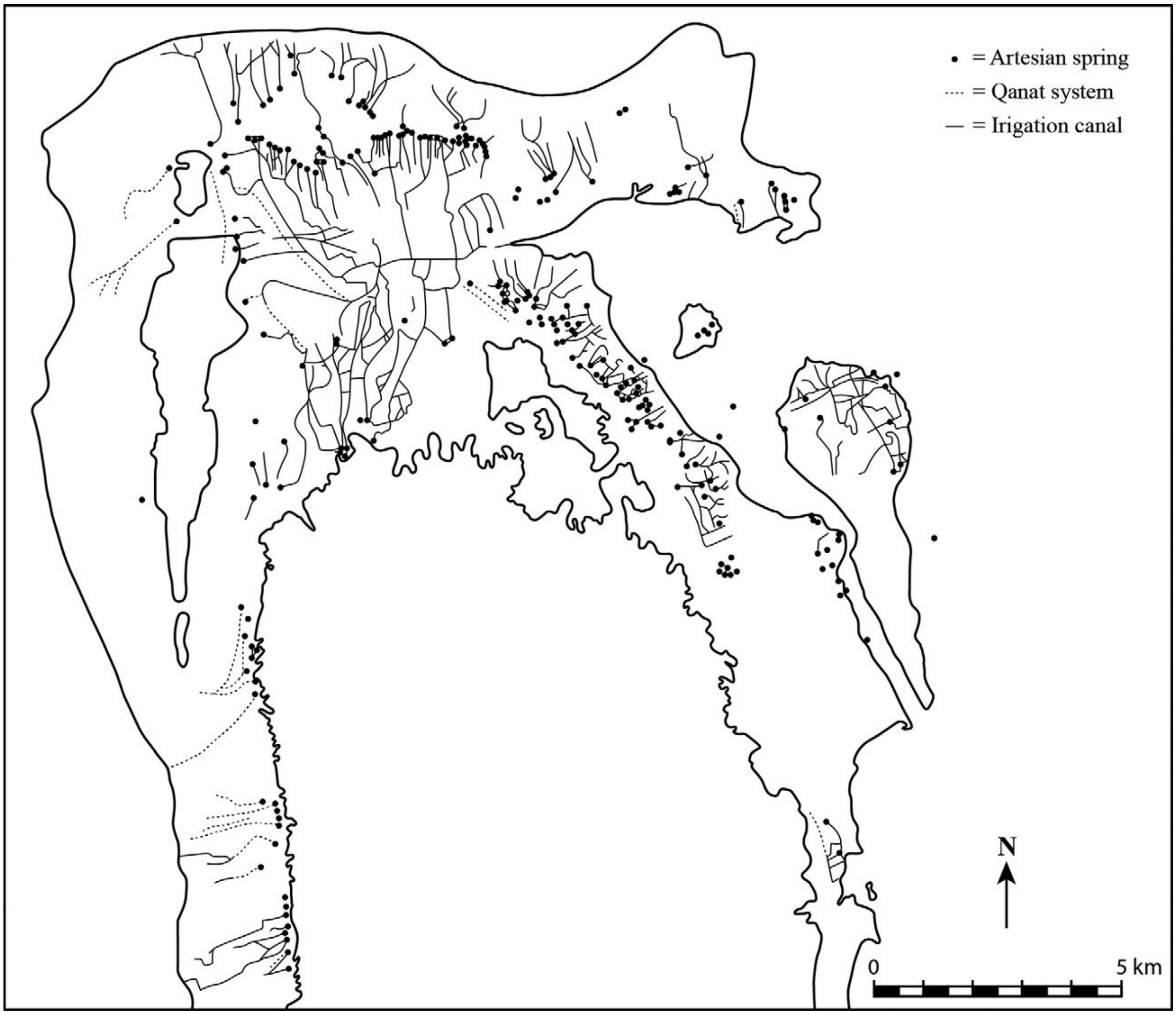

Figure 3. Irrigation systems in northern Awal (after Larsen 1983: fig. 15).

the channel. It also widened and narrowed in places implying that these were further design measures used to control water flow.

The channel had been constructed by being dug-out as a trench, exactly as Belgrave (1973: 94) had earlier surmised about how *qanats* in Bahrain were built, it was then roofed and covered with sand, and thus not excavated as a tunnel as we originally assumed. The internal channel construction was complex. The lower sides of the channel sloped out and were built of rough stone walling in a hard lime mortar on top of a base of large stones. The upper walls of the channel sloped in to meet at the apex and were made from large slabs of faroush. In most of the channel there was a second layer of faroush slabs above this, with a rubble infill of flint blocks and limestone cobbles between the two (**Figure 5**). In many sections there was also a thick layer of charcoal mixed with bitumen under the plaster and stone (up to 30cm depth) which we interpret as a water-proofing agent potentially indicating that the hydrophobic properties of charcoal may have been understood and exploited (**Figure 5**).

A total of eight vertical maintenance shafts were uncovered in the north *qanat* field which when emptied of their deposits were found to be stone lined and roughly circular with wall thicknesses of approximately 30-35cm, external diameters between 138-166cm and internal diameters between 79-119cm, and therefore indicating quite significant variation in diameter but conversely with fairly similar depths ranging between 224-320cm (**Table 1**). The tops of the maintenance shafts had originally been raised above the ground surface, again presumably as a sand control measure and their exteriors were plastered (**Figure 5**).

The *qanat* system was difficult to date as it contained very few artifacts and little material for C14 analysis excluding the charcoal used for waterproofing which

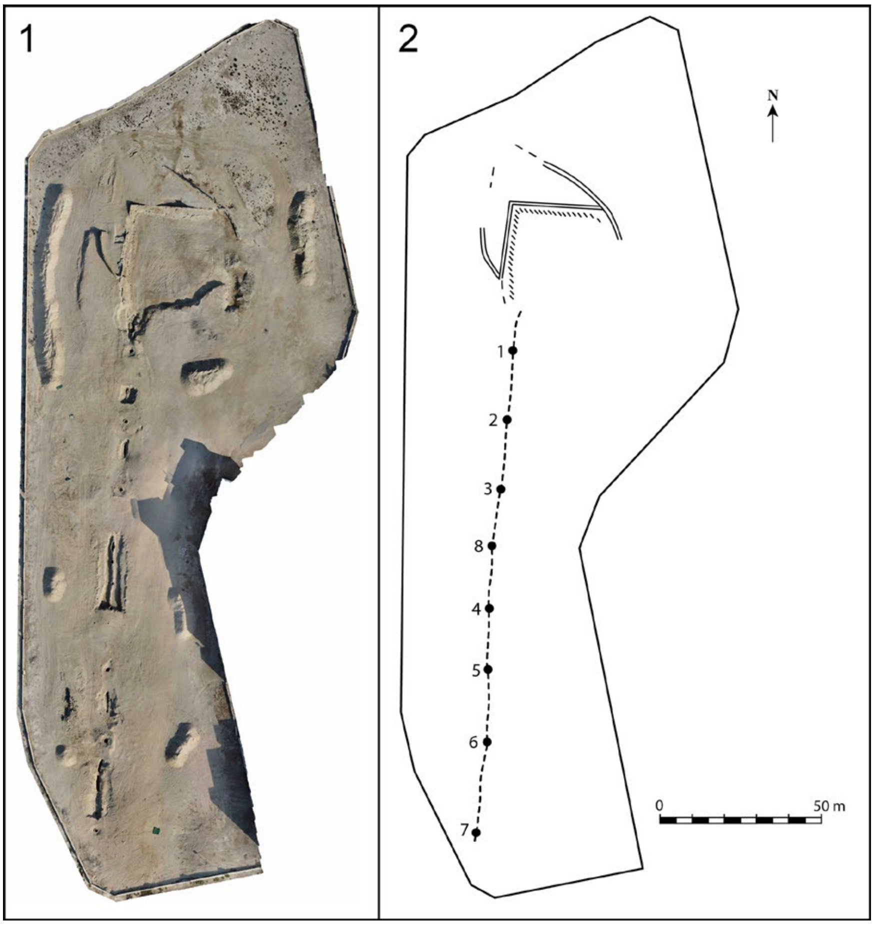

Figure 4. Hamad Town, northern *qanat*. 1. Drone image (photo. BACA). 2. Plan.

was deemed too contaminated to be processed. However, two radiocarbon dates were obtained: one from a piece of charcoal taken from within the mortar of the northern wall and the second from a piece of bone from the base of shaft 8. These samples were analysed by Beta Analytic using AMS dating methods. The charcoal from the northern wall produced a date range of 1802-1936 CE and the bone from shaft 8 produced a modern date of 1960s-1980s CE (**Table 2**) from which it was concluded that the bone was part of the modern rubbish infill, whereas the charcoal reading was accurate.

Ceramics were equally rare but from between Shafts 4 and 8 two sherds were retrieved and identified by Tait (2025: 22) as an undated Pink Limey Cookware sherd embedded in the *qanat* plaster, and a mid-18th to 20th century Grey Gritty Ware sherd, which would concur with the ceramics evidence from the building. Previously, Larsen (1983: 88) had suggested that 'medieval ceramics found associated with these irrigation structures point to intensified use during this same period', but at least in relation to the Um Jrai *qanat* this is inaccurate. However, Tait (2024: 21) did identify some ceramic evidence he inferred as attesting earlier activity around the spring, which we would refine as of 10th to 13th century date, and including two sherds of Hard Dense Earthenware, a single sherd of Turquoise Glazed Ware, and a worn Sgraffiato rim.

Therefore, based on the AMS dates and the ceramics we would interpret the Hamad Town *qanat* as of 18th-19th century date, at least in its current form. Finally, we would highlight the complex technical knowledge apparent in its construction which is also found in other sections of *qanat* that have been preserved and if this is extrapolated across the whole network mapped by Larsen (1983) attests considerable ingenuity and constitutes a remarkable achievement.

Saar

A second section of *qanat* survives in Saar (**Figure 1**) and we would draw particular attention to it as it appears to have been built using similar construction methods. As yet unexcavated or surveyed, it has been preserved for a length of approximately 50 m and in addition to having comparable maintenance shafts (**Figure 6**), seems to have the same arrangement of a double faroush slab roof infilled with rubble (**Figure 6**).

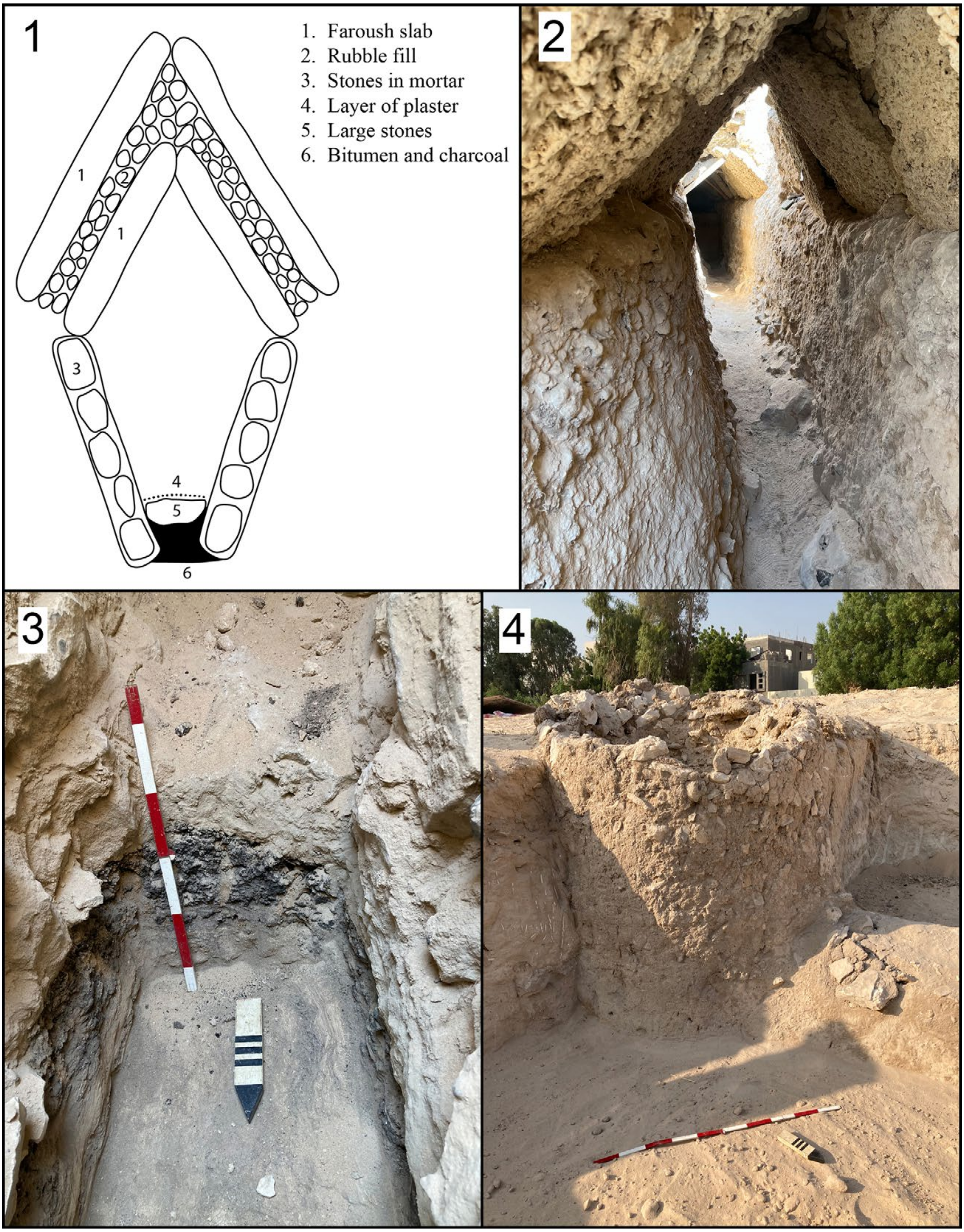

Figure 5. Hamad Town, northern qanat. 1. Construction. 2. Interior. 3. Bitumen layer at base. 4. Plastered exterior of shaft 4 (photos. T. Insoll).

Table 1. Hamad Town *qanat* maintenance shaft locations and dimensions

Shaft	Co-ordinates	Internal diameter cm	External diameter cm	Depth to base cm
Shaft 1	N 26.12925 E 050.49193	NS 104 EW 104	NS 166 EW 160	305
Shaft 2	N 26.12904 E 050.49192	NS 79 EW 92	NS 146 EW 153	239
Shaft 3	N 26.12885 E 050.49192	NS 98 EW 104	NS 156 EW 161	224
Shaft 4	N 26.12852 E 050.49186	NS 117 EW 104	NS 166 EW 160	310
Shaft 5	N 26.12837 E 050.49189	NS 113 EW 114	NS 160 EW 160	268
Shaft 6	N 26.12814 E 050.49186	NS 99 EW 119	NS 146 EW 171	320
Shaft 7		NS 83 EW 97	NS 138 EW 138	295
Shaft 8	N 26.12872 E 050.49185	NS - N/A EW 90	NS - N/A EW 160	Just shaft base in channel remains

Table 2. AMS Radiocarbon dates from the Hamad Town *qanat*

Area/context	Laboratory Number	Date (2 sigma calibration)
HAM 22 Interior wall mortar	Beta - 652034	100 +/-30 BP or Cal 1802-1936 AD
HAM 22 Shaft 8	Beta - 652035	Cal 1959-1985 AD

However, it awaits further research and has been listed as a protected archaeological site.

Another much shorter section of *qanat*, which may or may not have linked to the latter, was discovered in 2017, when it was accidentally unearthed during groundworks for the erection of a three-storey building. Fortunately, the landowner recognised its historical significance, and it has been preserved in the underground carpark of the building and he has plans to present the *qanat* to the public, to showcase the importance of irrigation canals in the region (**Figure 6**). Of interest is that although only a short stretch of this *qanat* survives it links to a larger chamber, approximately 180cm width and 400cm height which appears to have been the source of the water. This would appear similar to a larger chamber recorded by James Belgrave (1973: 94) in Shakhura village and described as a subterranean bathing hall through which ran a continual stream of cold water. Other small sections of this same *qanat* system in Saar survive to the east of the chamber with two openings for maintenance shafts found in neighbouring properties including the Wahat Al-Raja residential complex where the canal extends into the swimming pool area for approximately 5m.

We also have some ethnographic information on irrigation in Saar provided by the Danish anthropologist Henny Harald Hansen (1968) who spent several months in the village in 1960, prior to the decline of traditional agriculture. Presciently, she noted that Saar was ‘said to be the oldest village on the island of Bahrain’ (*ibid.*: 35) which has now been confirmed archaeologically through excavation to the south of the modern village where occupation was dated back to the Early Dilmun period, c. 4000 years ago (cf. Killick and Moon 2005). In the 1960s there remained four *qanats* running east to west which supplied the village, a palm garden, and 2 small *bustans* or vegetable gardens and the *qanats* fed into open canals in the plantation where there were also secondary places for washing. The primary washing places were at the *qanat* mouths at the edge of the plantations and were walled or hidden by ground elevation because they were used as washing places for women (Hansen 1968: 35). Thus providing us also with an interesting example relating to the social use of water which could not be reconstructed from archaeological data alone.

Also utilised for irrigation in another garden at Saar was a deep well where the water was lifted by a *shādūf*

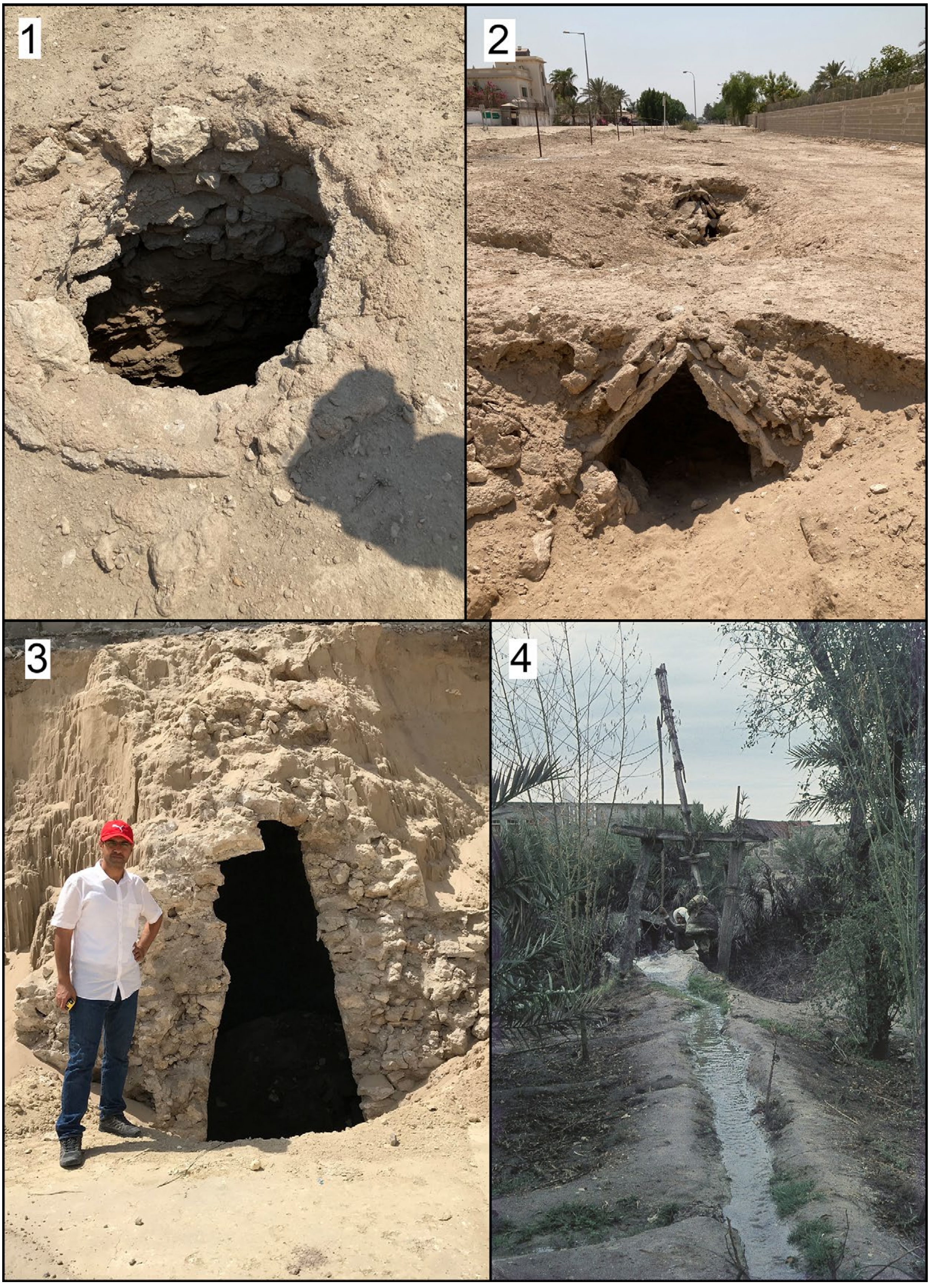

Figure 6. Saar. 1. *Qanat* maintenance shaft. 2. *Qanat* (photos. T. Insoll). 3. Entrance to underground chamber (photo. S. Almahari). 4. Shaduf in use, 1960s (photo. BACA).

with a palm trunk frame carrying a bar with a limestone weight at one end and a tanned sheep-skin bucket at the other and with which the water was initially transferred into a sloping hollowed out palm trunk which in turn fed into canals described as arranged in the shape of a rake (Hansen 1968: 35) (**Figure 6**). We also gain an idea of the canal size for Hansen (*ibid.*) further refers to their being dredged with a hoe of just 54cm length but having a blade of 21cm width by 22cm length, suggesting it matched the dimensions of the canal channels. These types of canals were also more recently considered by Rudolff and alZekri (2014: 85) who refer to these being of three types; *al-sāqiyah al-kabīra*, large deep channels up to an unspecified 'several metres wide', *al-sāqiyah al-saghīrah*, branch channels distributing water to farms, and *sāb*, smaller and more common channels, probably the latter type in Saar, and which were essentially private being within the farms, whilst the other two larger types of canal were better considered as public. However, unfortunately, they do not provide any information on the form, construction materials, or dimensions of the canals.

Bilād al-Qadīm

Archaeological evidence for varied water management infrastructure has also been recorded in Bilād al-Qadīm, the former Abbasid capital of Bahrain (**Figure 1**). At the Al-Hassan or Haroun Mosque mound, for example, the earliest structure in the sequence was a water channel, itself undated, but found within a small guardhouse or fort of 8th to early 9th century date and accessed by a steep plaster staircase up an internal wall leading to a plaster floor above the channel set with four circular indentations that may have been used to store water jars (**Figure 7**) (Insoll 2005a: 72). Water was also important in local tradition about this site with it recounted that a man called Haroun came to Bilād al-Qadīm to look for a wife but was unsuccessful and hence filled an adjacent well with lead weights so as to cause it to dry up and poison the water supply (Insoll 2005a: 34). Interestingly, considering the mythic quality to this tradition, there were 80 lead artifacts, largely coins or weights, recovered from the excavations in the neighbouring area surrounding the Al-Khamis Mosque

Figure 7. Bilad al-Qadim. 1. Al Hassan/Haroun Mosque. Steps leading to water channel and platform with indentations possibly for water jars. 2. Al-Khamis Mosque. Ablutions area and column section (photos. T. Insoll).

(Insoll 2005a: 306), raising the intriguing question as to whether this was merely coincidental, or does it provide some degree of correlation for the local narrative about the polluting of the water supply?

The Al-Hassan/Haroun channel was also part of a network recorded across the area of Bilād al-Qadīm, some sections of which, as with the former, seem to have been open rather than closed *qanat* type systems (cf. Insoll 2005a: 95). An exception was provided by a covered channel which either supplied or disposed of water from a large ablutions area directly north of the Al-Khamis Mosque. The ablutions area itself was formed of an artificially dug well or cistern of 320cm depth accessed by three walled staircases (**Figure 7**), with the channel in the fourth northern wall, and with a stone and plaster bench inside that may have been utilised whilst drawing water. Three cylindrical column drum sections and a fourth square column base suggested the ablutions area had also been roofed (Insoll *et al.* 2016: 233-234) (**Figure 7**).

However, the most important spring in Bilād al-Qadīm was Ain Abu Zaydan which is now derelict but was described as recently as the mid-1980s as having a 'most beautiful mosque' by Lewcock (1986: 493) (**Figure 8**), and as in 'a reasonable state of repair' but, sadly, this is no longer the case (**Figure 8**). This mosque, which Lewcock (*ibid.*) also ascribed a tentative date of the 17th century to is built above a spring (**Figure 8**), and Belgrave (1973: 89) refers to the 'Abu Zaidan Mosque' being 'much used by the Shia people of Manama, especially by the women during weddings'. Whilst in the late 19th century (cf. Insoll *et al.* 2016: 239), the British traveller Theodore Bent (Rice 1984: 78) referred to the spring as 'reserved for the private use of Sheikh Esau and his family', with adjacent 'a tiny mosque', and his wife, Mrs J. Theodore Bent added further detail, writing in February 1889, that it had 'a wall round it and partly roofed in with a pillar standing in the water, irregular, pretty and rather dirty. Close by was a sort of 'loggia' where he prays, takes coffee and spends the day' (Bent 2010: 15). These references show how the use of Ain Abu Zaydan has changed over time, but also how throughout the centuries it has remained important since the first historical reference to it, by Al-Idrisi in the mid-12th century in his book *Nuzhat al-Mushtaq* (Al-Doy 1993: 159).

Yet, it also seems that Ain Abu Zaydan has a considerable pre-Islamic history which is suggested both by the incorporation of massive masonry blocks in the side walls of the pool and four stone drums at the base of a column supporting the floor of the overhead mosque. Moreover, one of these, the second from the top, appears to be an upturned altar or libations table complete with carved spout to allow blood and sacrificial liquids to flow out (**Figure 8**). A more prosaic interpretation, that this had been part of an oil press or grinding mill being less applicable, as one of us has previously noted (Insoll 2005b: 79), in the absence of analogies for such equipment. In fact, parallels can be found, albeit in a more stylised form, in the circular altar block from Temple I or II at Barbar, i.e., c. 2000 BCE (cf. Hellmuth Andersen and Højlund 2003: 61-62, figs. 62, 63, 64). And we can suggest that perhaps the inversion of the altar, if that is what it was, indicates the appropriation of an earlier, possibly Dilmun, sacred space by the much later Islamic Mosque, as part of a process of Islamisation.

Nevertheless, this remains hypothetical for excavation of the spring mouth found nothing dateable and only a handful of water-worn sherds (Insoll 2005b: 81). Much larger assemblages of ceramics, primarily of 11th-13th century date, with smaller quantities of 9th-10th and 14th century ceramics also present (cf. Insoll *et al.* 2016: 226-229; Insoll 2018: 15-17), were obtained from west of the extant pool in an area that would have formed the bank of a larger 'natural' pond that existed at Ain Abu Zaydan before it was contained within the current smaller tiled pool. Test excavations revealed at their base a channel of c.80cm width and a variable 7-18cm depth cut into the bedrock and a C14 date from charcoal from the channel fill was obtained of Cal 800 to 755 BCE (Cal BP 2750 to 2705, 2 sigma calibration, Beta 409135) (Insoll *et al.* 2016: 224-225). Initially, it was unclear if this was natural or human-made and subsequent larger scale excavations (AZ17, **Figure 9**) 4m north also uncovered part of a channel suggesting these were for water supply and likely connected to the Ain Abu Zaydan spring (**Figure 9**). They then fell into dis-use and were filled with rubbish prior to the mosque being built (Insoll 2018: 8). The date of these channels, nonetheless, remains uncertain and we suggest, based on the ceramic evidence, that they are Islamic and that the C14 date be disregarded as possibly based on old wood in the absence of any ceramic evidence to correlate it. It is also feasible that the extant open irrigation channels recorded in the adjacent Shaikh Isa's palm plantation west of Ain Abu Zaydan may originally have formed part of the same system (cf. Insoll 2005a: 22-23).

The results of the archaeological investigation also indicated that the Bilād al-Qadīm waterscape was not entirely benign for analysis of the micro molluscs from three contexts dated to between the mid-11th to 13th centuries within a domestic and commercial complex excavated east of the Al-Khamis Mosque revealed the presence of disease vectors linked with water (Insoll and Hutchins 2005). These included *Melanoides*, the vector for the Oriental lung fluke (*Paragonimus westermani*) and the Chinese liver fluke (*Clonorchis sinensis*), and *Bulinus*, the vector for bilharzia (*Schistosomiasis haematobium*). Both are species of water snails, *Melanoides* living in

Figure 8. Ain Abu Zaydan. 1. The mosque and spring in 1924. 2. The mosque and pool in 2010. 3. The inverted possible sacrificial altar stone in the column (photos. T. Insoll).

fresh and brackish water and *Bulinus* in fresh water (Insoll and Hutchins 2005: 583), with the latter, for example, carrying the bilharzia disease larvae which is then released into the water supply thus infecting people through penetrating their skin as they bathe, swim, wash, clothes etc. (Lambert-Zazulak *et al.* 2003: 231) and although we lack historical records for the medieval period, it is known that bilharzia was 'endemic' through to the mid-20th century (Faroughy 1951: 20), along with other diseases with a water-link, notably malaria, as Charles Belgrave (1960: 89) records, as well as dysentery. Hence whilst we would observe that this aspect of the archaeology of water management and irrigation technology – paleoepidemiology – appears to have been almost completely neglected, we would contend that it must also have been a crucial factor impacting on how effective these systems were and the duration they were used for and is a subject which we would stress merits investigation in other regions.

Other Springs and Wells

There are numerous other springs in Bahrain whose locations were recorded in, for example, the *Gazetteer*

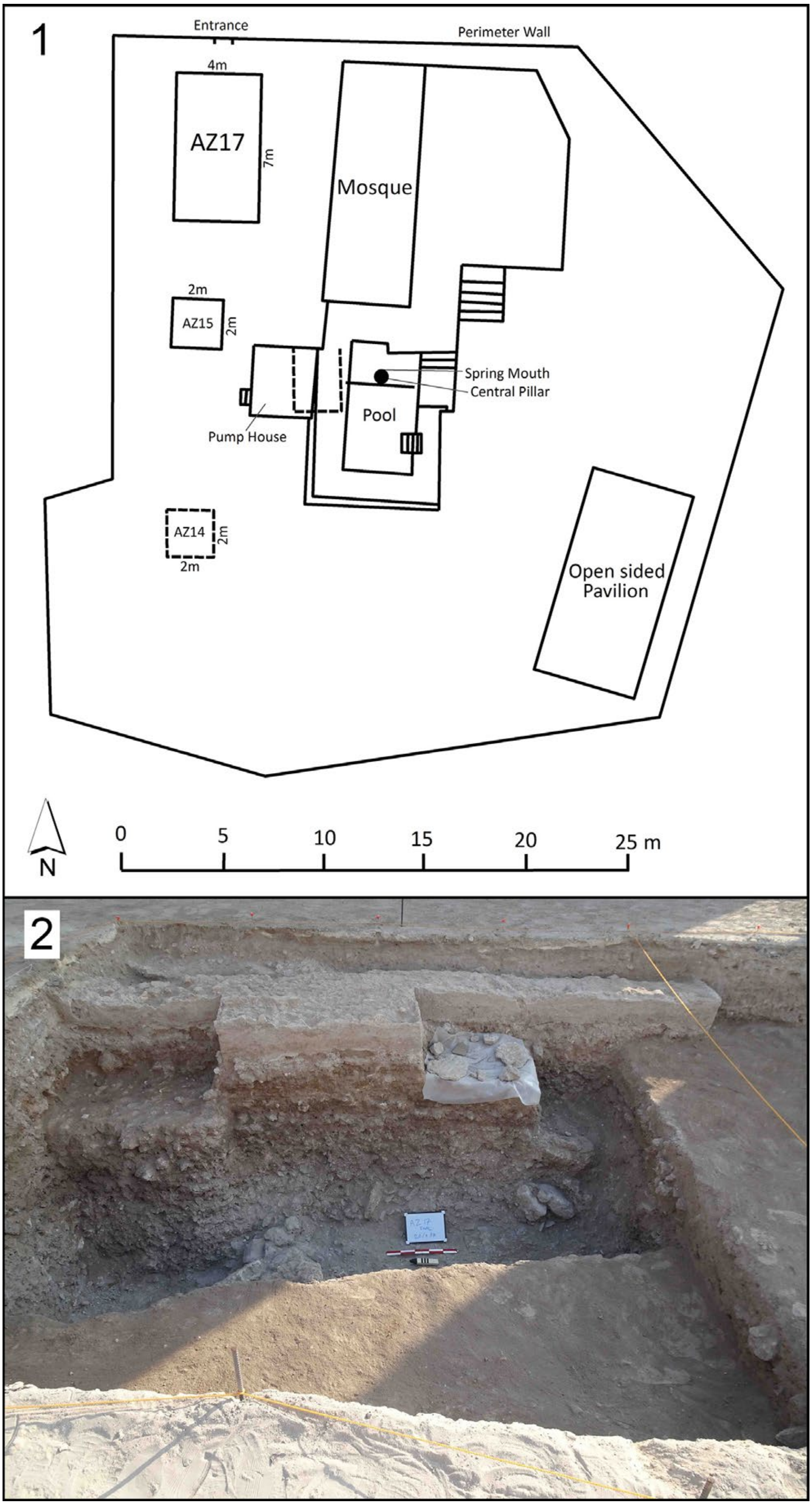

Figure 9. Ain Abu Zaydan. 1. Plan of the complex with excavation units indicated. 2. AZ17. The water channel (photo. T. Insoll).

of the Persian Gulf, 'Omān, and Central Arabia by Lorimer in 1908 (Lorimer 1908). Although this provides a useful record (**Table 3**), it does not dwell on their history or physical remains or provides any description other than a brief mention of Ain Abu Zaydan having a tank under the mosque which was then used by all the notables in Bahrain in hot weather (Lorimer 1908: 299), and that there were ruined houses in "a meadow-like"

Table 3. Abridged list of wells and springs in Bahrain provided by Lorimer (1908).

Spring	Description
'Adhārī	'Magnificent spring'...'water is extensively used for cultivation' (p.230)
'Aqala	Well, c.11km in an unspecified direction from Rās al-Barr (p.230)
'Amar	Well, c.5km south-southwest of Jabal ad-Dukhān (p.230)
Bartūfi	Spring on coral reef (presumably a *kawkab* [see below]) on northwest corner of Awal (pp.213, 230)
Dār	Spring, near Jiddhafs (p.230)
Dār al-Manādil	Well, c.800m south of al-Jaw (p.230)
Faraihah	Spring, Māhuz (p.230)
Kawkab Fasht Khor	Spring, on coral reef c.11km off northwest coast of Awal, used by pearl divers and then yielding up to 2450 litres of freshwater per day (p.554)
Um Ghuwaifah	West of Rifā' and water considered 'to be the best in Bahrain' (p.230)
Hafīrah	Well, c.5.5km southeast of Jabal ad-Dukhān (p.230)
Hunainiyah	Two wells just south of Rifā' within an enclosure and with donkey operated winding gear to draw water (p.230 and adjacent un-numbered figure)
Harta	Spring, c.800m southeast of Māhūz (p.231)
Um Jrai	Spring connected to a 'falaj' (*qanat*), c.5.5km west of Rifā' supplying Karzakan [see above] (p.231)
Khālid	Well, in Rifā' (p.231)
Mālikīyah	Spring connected to a *qanat*, c.3.2km northeast of Mālikīyah (p.231)
Maqāba	Spring, near Maqāba
Mattalah	Well, c.2km in an unspecified direction from Rās al-Mattalah (p.231)
Muwailghah	Unspecified, brackish water source used for irrigation near Muwailghah
Qār	Well, next to bitumen deposits, c.5km south-southwest of Jabal ad-Dukhān (p.231)
Qarain-adh-Dhabbān	Well, c.800m in an unspecified direction from Rās al-Qarain (p.231)
Qassarī (Ain al-Ghassari)	2 large springs, in Bilād al-Qadīm (p.231)
Qumri	Spring, c.3.2km south of Tūbli (p.231)
Rumaidhah	Well, 12km east of Rifā' (p.231)
Sabīyah	Spring, connected to a *qanat* 4km east of Rifā' (p.231)
Sāfa	Spring, connected to a *qanat* c.5km north-northeast of Rifā' (p.231)
Sāfirah	Well, in a rawda with house ruins, c.3.2km southwest of Rifā' (p.231)
Saiyid	Spring, in Tūbli (p.232)
Saiyid	Spring, north of Saar (p.232)
Sha'um	Spring, near Māhuz (p.232)
Shabāfah	Spring, c.5km east of Rifā' (p.232)
Sharaibah	Marine spring (kawkab) opposite Sharaibah (p.232)
Summān	Well, c.9.5km north of Rās al-Barr (p.232)
Tashshān	Spring, at Tashshān (p.232)
Um Yādar	Well, c.11.2km north of Rās al-Barr (p.232)
Yūsuf	Well, c.3.2km east of Jabal ad-Dukhān (p.232)
Abu Zaydan	See above

rawda at Sāfirah (*ibid.:* 231) suggestive of archaeological remains. More historically inclined is Serjeant's (1993) study of customary irrigation law who acknowledges Lorimer's list of springs but notes that the total was in fact 155 including the offshore springs, or *kawkab*, which were also a source of freshwater, and 29 of which were recorded during an intensive survey of all known locations of these springs completed in 1979 (cf. Anon 1980). Moreover, Serjeant also provides additional detail on some of the sites and features already discussed including, for example, that offerings used to be left at Ain Abu Zaydan, which would concur with the hypothesis we previously advanced, as well as underground water channels (*qanats*) running from Sadad to Karzakan, and at Mālikīyah (*ibid.*: 475).

Yet we still lack a detailed description of their physical infrastructure, history, and certainly archaeology, and there are notable omissions in Lorimer's list, such as Ain Buri, unless it is recorded under another name. This spring is still in use today and the surrounding bedrock appears to have been cut and then lined, in part, with substantial stone blocks (**Figure 10**), as at Ain Abu Zaydan, but it is undated and needs archaeological investigation. Another important but as yet archaeologically unexplored terrestrial spring is 'Adhārī, south of Bilād al-Qadīm. This was also described by Al-Idrisi, and Serjeant (1993: 476) also refers to the importance of 'Adhārī, and notes that local tradition suggested it was excavated in the Umayyad period, 'but there is no known evidence to support this belief", which is correct in the absence of any archaeological material indicating Umayyad occupation in nearby Bilād al-Qadīm (cf. Insoll *et al.* 2016). Thus, nothing is as yet known archaeologically about the history or uses of 'Adhārī but another local tradition records that a young, pure-hearted girl struck the ground with her foot causing sweet water to gush forth. This is a story that originates from popular oral history, and one authoritative source that discusses it is the *Encyclopedia of the History of Bahrain, Part II*, a work compiled by a team of researchers under the supervision of Dr. Muhammad Hassan Kamal Al-Din, first published in 2009, and which can be found on page 200.

However, we do have a brief reference to 'Adhārī in Capt. E.L. Durand's report on the first survey of Bahrain's archaeology in 1878 where he referred to it as supplying 'many miles of date-groves through a canal of ancient workmanship' which was about 3m in width, 60cm in depth (**Figure 10**), and fed by the spring of 26.5m length by 20m width (Rice 1984: 17). Interestingly, even then it seems to have been in partial disrepair as he also described the stone as 'falling in' (*ibid.*), in places. 'Adhārī was restored at some point in the late 1920s or early 1930s under the direction of the British Advisor Sir Charles Belgrave (1960: 137) who records that the work included the construction of a viewing platform and diving board, coffee shop, and rebuilding of the mosque overlooking the spring, and the basin repaired and presumably lined with cement. 'Adhārī later became part of a theme park, with the spring converted to a modern swimming pool and the complex is currently closed.

We also lack information on the archaeology and history of another spring to the northeast of 'Adhārī, Qassarī or Ain al-Ghassari, similarly in Bilād al-Qadīm, and referred to by James Belgrave (1973: 147) as a 'lake' as well as a 'pool' and which historical photographs indicate was of a substantial size and also linked to a canal (**Figure 10**). Durand also remarked that the water from 'Adhārī was 'not perfectly sweet' (Rice 1984: 17) and that the best water was obtained from Umm Koefih and Hunainiyah wells in the Rifaa Hills in the centre of the main island of Awal. Again, we know little about these wells which Larsen (1981: 90) describes as 'hand-dug' and 'located at the mouths of wadis draining the western slopes of the central dome'. A partial exception is provided by another example of hydraulic infrastructure in the same area at Berak Bint Bin Musa, east of Awali Golf Club, where a number of small dams built of limestone, approximately 3m in height, and accessed by a stone staircase, were constructed in a wadi probably used to hold water in the land behind the dams to grow crops (**Figure 10**). Likewise, the only example of a tank or cistern that we have found, at A'ali, also awaits archaeological investigation. Built to harvest rainwater, the rectangular tank measures c. 38m length, 6m width, and 2m in depth (**Figure 10**), and although again undated it may originally have been linked with the Islamic archaeological site (mid-8th to 9th, 11th to 12th centuries) located some 250m to the east (e.g., Sasaki and Sasaki 2011) and then continued to be used and maintained. Whilst our knowledge of springs and irrigation in Muharraq island is equally minimal (e.g., Ain Raya, Ain Bin Hendi, Ain Al Tinah).

A recent exception to the general absence of archaeological investigation is, however, provided by excavation of a *kawkab*, on Al-Sayah Island c.1.5km off the northwest coast of Muharraq Island (cf. Carter 2024). This was found to be an artificial island constructed of coral block and rubble infill forming a platform, c.67m by 52m and raised 168cm above the seabed, inside a stone enclosing wall with at its centre a circular cistern containing a spring and next to this a floor impressed with traces of foundations probably from a *shādūf* used to load water into waiting boats that appear primarily to have been involved in pearling (*ibid.*: 27-31) (**Figure 11**). C14 dates and ceramics indicated that it was in use between the mid-6th to early 8th centuries and it is a unique discovery not just in the Bahraini context but in relation to the whole Arabian/Persian Gulf,

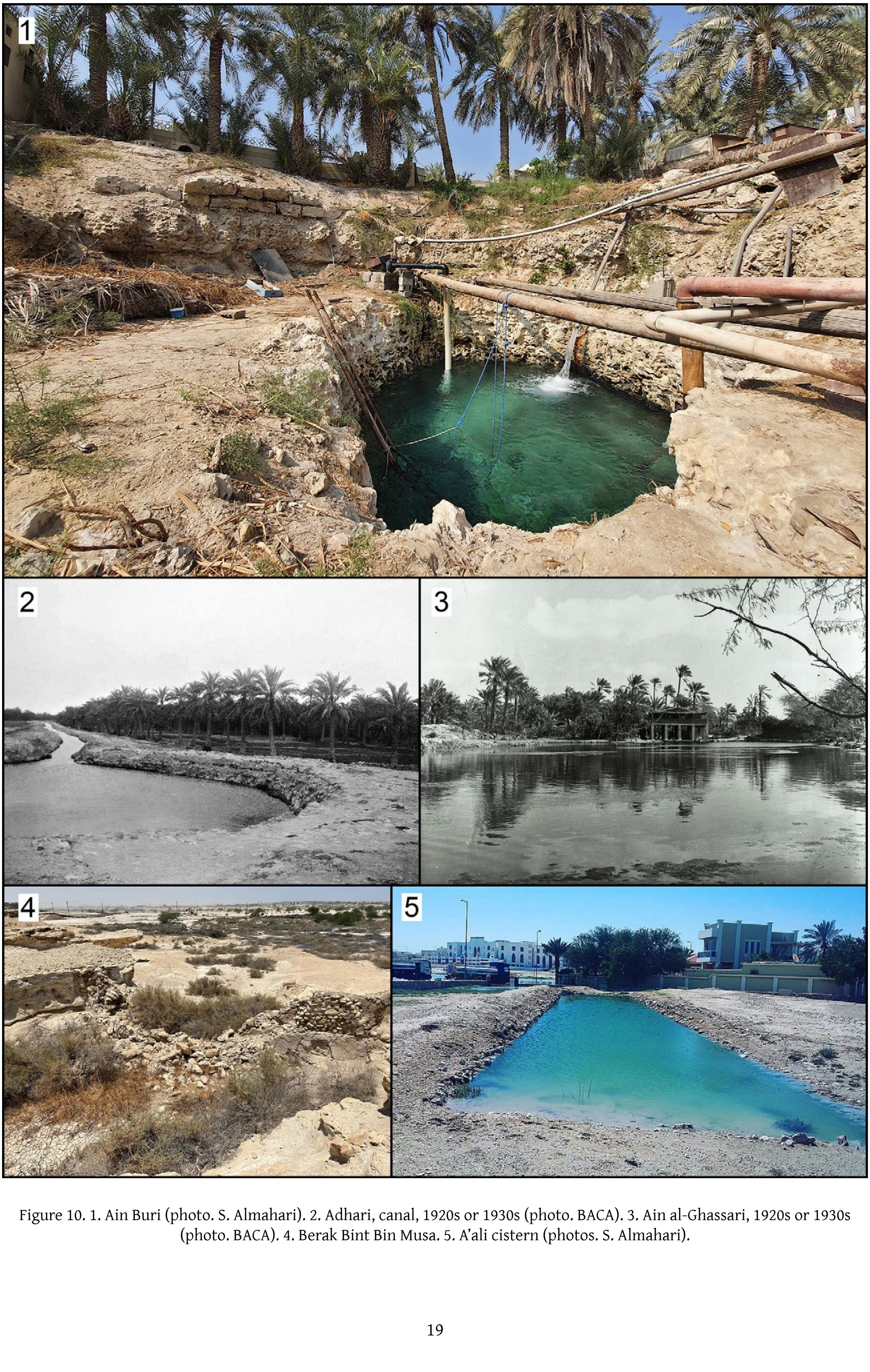

Figure 10. 1. Ain Buri (photo. S. Almahari). 2. Adhari, canal, 1920s or 1930s (photo. BACA). 3. Ain al-Ghassari, 1920s or 1930s (photo. BACA). 4. Berak Bint Bin Musa. 5. A'ali cistern (photos. S. Almahari).

Figure 11. Sayah Island. Plan of walls and other features visible on the surface (courtesy R. Carter).

and it seems to our knowledge, elsewhere as well. It also proves that archaeological investigation offers possibilities to accrue significant information about otherwise unknown or minimally historically recorded hydraulic infrastructure.

Discussion and Conclusions

The evidence from Bahrain attests the rich but threatened archaeological waterscape of the Kingdom. We see this as of significant importance for it is not only the heritage of the Kingdom of Bahrain but forms part of the patrimony of the Islamic World, as well as in a wider global context, and as such our key recommendations are that :

1. A full inventory of the remaining traditional hydraulic infrastructure in Bahrain is made.
2. A strategy is developed to safeguard and present key examples of this within a framework of water heritage and tourism.
3. That the Bahraini public are sensitised to the variety and value of the archaeology of water through the media, school curricula, and through investment in some of the key sites.

These may also help in addressing the many challenges that have emerged over recent decades including the over-drilling of artesian wells that led to the reduction in the aquifer meaning 'some of the gardens in the south of the island (Awal) dried up', as Serjeant (1993: 472) recounts, as well as the development of a more selfish attitude to the use of treated sewage effluent, an alternative water supply more recently utilised, and contrary to community minded traditional irrigation practices (Rudolff and alZekri 2014: 93), and customary law (cf. Serjeant 1993). And we believe that this could be achieved through simply increasing awareness of the importance of water, as was once commonplace, rather than it being regarded as an infinite resource, literally 'on-tap'. Developing such awareness, we would hope, may also help in addressing the challenges facing

Figure 12. 1. Ain al-Hakim. 2. Barbar South. 3. Budaiya (photos. T. Insoll).

both the archaeological record, and living heritage of hydraulic infrastructure in Bahrain. With a pertinent example of the former provided by the Ain Al-Hakim spring in Hamad Town, which is now at the centre of a modern housing development, but is at least safeguarded, though is in a very poor condition (**Figure 12**) and needs restoration which if achieved would help in highlighting the importance of natural springs in the Bahraini environment. Whereas the latter is exemplified by the impending threats facing the spring at Barbar South (**Figure 12**) as a consequence of housing development which also means part of the archaeological site will disappear.

Yet it is possible to be optimistic for the contemporary importance of water is being recognised at a Government level as evident on the website of the Electricity and Water Authority in Bahrain, where there are tips both for conserving water and for using it more efficiently (web reference 1). Less apparent is a recognition of its historical importance (web reference 2) but this is now beginning to be addressed with the first tangible indication at a Government level provided by the recent decision of the Ministry of Municipalities, working with the Bahrain Authority for Culture and Antiquities, to preserve the excavated sections of the Hamad Town *qanat* and present them to the public as the centrepiece of a new park, the first to include archaeology in this way in Bahrain. This is a significant step which we believe could be enhanced by restoring some of the surviving springs starting with Ain Abu Zaydan and whilst we acknowledge that it is unlikely these springs could be brought back into 'natural' use because of aquifer depletion, it would be possible to artificially fill these, if this was deemed an important element in their presentation, as was successfully achieved through the integration of historic water infrastructure into the agricultural park at Budaiya (**Figure 12**).

To conclude, we believe that benefits will certainly be derived from looking to the past so as to underline the **fundamental value** of water of which our ancestors – Bahraini or otherwise - were so aware and Dr Nicholas Tait for preparing some of the illustrations.

Acknowledgements

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Chapter 3.
Archaeology of Water in Islamic Southern Arabia

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Introduction

Water management systems in the Islamic World build on thousands of years of experience in engineering, constructing, and operating systems in different contexts. Like those of other regions, histories of water management systems in Southern Arabia, referring in this chapter to Yemen and Oman, offer a wide range of important insights and lessons relevant to present and future challenges of agriculture, food and water security, flood control, and human health. In addition to archaeological investigations, the work of anthropologists and historians who have focused on Islamic agriculture and water management in Southern Arabia, including D.M. Varisco (e.g. 1983; 1996; 2009) and J.C. Wilkinson (e.g. 1977; 2002), has generated considerable literature. Many traditional water management systems are highly sustainable by present standards and can be operated locally, but these systems are also very vulnerable if not appreciated, valued, and maintained (Pietsch and Mabit 2012; Varisco 1991). Traditional systems not only need to be sustained but also revived and reconstructed in ways that contribute to equitable livelihoods, peace, prosperity, and resilience to climate change (Al-Hebshi 2019).

Water exerts understandably major influences in arid regions spanning political, economic, ideological, and religious spheres of life, and trajectories of long-term histories are often shaped by a range of environmental and social factors that vary substantially through space and time. Justifiably serious concerns about modern human exploitation of water resources have led to predictions that parts of Yemen, including the capital Sana'a, will catastrophically run out of water (Weiss 2015). The phrase 'run out of water' quite obviously implies that at some point there will be no water available; although there have been times when municipal water systems ceased to operate for days or weeks (Caton 2013: 285), the situation in Yemen over the past few decades has been a more slowly unfolding but nevertheless dire tragedy in which gradually increasing water scarcity contributes to disputes and violent conflicts, outbreaks of waterborne illnesses, and becomes so expensive that only comparatively wealthy segments of the population can afford sufficient water access (Varisco 2019). Borehole drilling and water pumping technologies promoted by international development agencies, particularly in the 1970s and 80s, have often had the unintended consequence of drawing down aquifers (Lichtenthäler 2003), making emphasis on sociopolitical contexts and sustainability of utmost importance. The situation is very different in Oman, where political stability has contributed to prosperity and far more conscientious management of water resources. A rapidly growing population with increasing demands for water has necessitated desalinization, but even so, there remains widespread awareness of the value of traditional water management technologies and practices (Bandyopadhyay and Mershen 2022; Khaneiki *et al.* 2024).

Topographic, Climatic, and Environmental Conditions

The terrain, climates, and environments shaped traditions of water management in Southern Arabia during pre-Islamic through Islamic times. Large expanses of the relatively flat Rub' Al-Khali Desert cover substantial parts of Southern Arabia, but high igneous and metamorphic mountains reach over 3000m in western Yemen, rugged limestone highlands stretch 1000km west to east over Hadramawt, Mahra (Yemen) and Dhofar (Oman), and the geologically diverse Al-Hajar Mountains similarly rise to over 3000m in northern Oman. Although lowland desert areas receive very little rainfall, the highlands of western Yemen receive over 800mm/yr (Bruggeman 1997: Appendix 1), with up to 330mm/yr falling in the highest elevation areas of northern Oman (Kwarteng *et al.* 2009: Table 1). Particularly given the cooler average temperatures at higher elevations, some parts of Southern Arabia have not historically faced acute water shortages as might be expected in such an arid region. Water management strategies thus vary widely according to topography, landforms/landcover, temperature, precipitation, and seasonality.

Importantly, environmental conditions have varied substantially through time potentially contributing to major societal changes. Based on recent analysis of the latest paleoclimatic records, Fleitmann and colleagues (Fleitmann *et al.* 2022, Haldon and Fleitmann 2023) observe that the decline of the Himyarite Kingdom in Yemen during the 6th century CE (all dates are CE unless otherwise specified) occurred amidst drought associated with global cooling of the Late Antique Little Ice Age (LALIA). Climatic conditions that resulted in changes in water availability and associated agricultural productivity undoubtedly had an impact on ancient societies, but the exact consequences of climatic and environmental oscillations are complicated to interpret and call for continued investigation.

Water and Agriculture in Islamic Southern Arabia

The early Islamic era led to an undeniably dramatic transformation, not only with respect to religion but also of social, cultural, economic, and political life across a wide swathe of the world. Over the past half century, considerable research has focused on the spread of new crops, agricultural practices, and water control technologies during early Islamic times, a phenomenon sometimes referred to as the Islamic Agricultural Revolution. In a highly influential paper and subsequent book, Andrew Watson (1974, 1983) argued that a dramatic transformation in agriculture accompanied the spread of Islam from the 8th through 13th centuries, including major changes in farming practices and diffusion of crops including 17 that he specifically listed: rice, sorghum, durum wheat, sugar cane, watermelon, eggplant, spinach, artichoke, taro, sour orange, lemon, lime, banana, plantain, mango, coconut, and cotton. Watson's assessment has been subject to considerable critique and debate, including through recognition that some of the aforementioned crops had already spread prior to Islam (e.g. Decker 2009), but most agree that agriculture underwent substantial transformations associated with the spread of Islam (Squatriti 2014).

Understanding what crops and water management practices appeared and spread with Islam requires a foundational understanding of what preceded Islam. Unfortunately, the specific details of pre-Islamic agriculture in Southern Arabia are not very well-known, which makes it difficult to evaluate what was present before and what was introduced during Islamic times (Varisco 2023). We do know that the earliest water management appeared in Yemen during the 4th millennium BCE, including small-scale irrigation in Hadramawt (Harrower 2020) and terraces in western Yemen (Wilkinson 1999). At roughly the same time, in the late 4th and 3rd millennium BCE, crops including wheat, barley, broomcorn millet, lentils, peas, and chickpeas appeared in western Yemen as demonstrated by finds of charred seeds at archaeological sites in Dhamar (Ekstrom and Edens 2003). The details relating to the appearance of many other crops are complex. Archaeobotanical work in the 1980s and 90s that relied on seed impressions in pottery (Costantini 1984, 1990) are widely viewed as unreliable. Similarly, historical texts' references to crops can be challenging to interpret and only rarely pertain to pre-Islamic times. Charred seeds are most reliable but have only been recovered from relatively few excavations (de Moulins *et al.* 2003). Recent studies focusing on the archaeobotany of the Arabian Peninsula are generating critical new evidence that shows some crops, such as sorghum may have, indeed, spread during the early centuries of the Islamic era (Dabrowski *et al.* 2024). Concordantly, archaeological evidence and ancient pre-Islamic texts also offer a wide range of insights about irrigation technologies and the complexities of engineering and managing different agricultural systems (e.g. Maraqten 2017).

In conjunction with archaeological research, one key means to examine agricultural practices and water management during Islamic times involves analyzing the work of early Islamic scholars. Most notably, the 10th century geographer and historian Abū Muḥammad al-Ḥasan al-Hamdānī offers a wide range of information about irrigation works and agriculture in Yemen (Varisco 2009). Born to a Yemeni family involved in the camel caravan trade between Sada and Mecca, Al-Hamdānī is thought to have written at least 23 works (Varisco 2009: 384-385). Al-Hamdānī's 8th book *Al-Iklil* 'The Crown' on the Antiquities of South Arabia includes passages on major waterworks in Yemen including the Great Dam at Ma'rib (Faris 1938: 34-35). His *Sifat Jazirat al-Arab* 'Geography of the Arabian Peninsula' includes discussion of crops, seasonality, and water management practices (Müller 1884). A few centuries later, the Rasulid Dynasty of 13th to 15th century Yemen produced what Varisco describes as the 'richest corpus of agricultural texts for any medieval Arab society' (Varisco 1994: 3). One Rasulid almanac analyzed and published by Varisco deals with calendars, astronomy, meteorology, water sources, and environmental circumstances, but its most central topic is agriculture (Varisco 1994). This text demonstrates broad interests in agricultural science and a wealth of information on the geographic distribution, seasonality, and quality of domesticated and wild plants, including grains, herbs, fruits, vegetables, flowers, aromatics, and textiles. Correspondingly, Hehmeyer's archaeological research on water engineering and management surrounding the historic city of Zabid, Yemen – founded in 820 – richly complements textual records illuminating a long and sophisticated history of Islamic water management, including during the Rasulid Dynasty (Hehmeyer 2019: 59-153). Although much remains to be determined about the nature and timing of different crops and agricultural technologies, appearance in Southern Arabia, the considerable body of knowledge that archaeologists and historians have generated thus far already demonstrates a florescence of innovation during the early Islamic era.

Types of Water Management Strategies and Technologies

A wide range of water management strategies have prevailed in Southern Arabia during Islamic times (Varisco 1996). Many technologies resemble techniques employed in other regions, but they all require adaptation to the particular social and environmental landscapes of Yemen and Oman. In high elevation, high precipitation areas, rainfed agriculture (*aqar*) is most common, but relying on rainfall alone leaves farmers vulnerable and supplementary forms of water supply can expand the range of crops that can be grown and can mitigate uncertainty. Indeed, rainfed agriculture does not appear to have been the primordial norm and other forms of spring fed agriculture appear to have been the earliest means of cultivation (Harrower 2016). One way to organize the different types of strategies and technologies is to start with the demonstrably earliest, least labour-intensive techniques and progress toward more organizationally and technologically complex systems.

Yemen and Oman utilize some of the same strategies and technologies, but the particulars vary in different areas. The term *falaj* (pl. *aflaj*), which literally means to divide, is used throughout Oman and the United Arab Emirates (UAE) to refer to water management systems illustrating the importance of traditions governing water access, distribution, and sharing that involve dividing water amongst users. *Falaj* systems are sometimes categorized into three different types: *Ayni Falaj, Ghayli Falaj, and Daudi Falaj,* which refer to systems that obtain irrigation water from springs, wadi baseflows, and underground aquifers, respectively (Al-Ghafri 2008: 76-77). In any particular location, irrigation systems vary substantially, but as described below, techniques and terminologies used in Yemen and Oman do bear some important resemblance to one another.

Springs (‘Ayn *and* Ghayl*)*

Exploitation of water flowing from natural springs is arguably one of the oldest and most sustainable water management strategies in Arabia (Harrower 2016: 64-72; 97-102). The common Arabic term for spring, *ayn* (pl. ‘*ayun*) is used across Southern Arabia to designate natural water flows often from rocky outcrops in mountainous areas. Meaning of the term *ghayl* (pl. ghuyul), which is also common in Yemen (**Figure 1**) and Oman, varies over time and in different places (Hehmeyer 2019; Varisco 1996), but often refers to more copiously flowing baseflows found along wadi drainages (Al-Ghafri 2008: 76-77).

Figure 1. *Ghayl* water flow (baseflow) at Ghayl Omar along Wadi Idm, Hadramawt, Yemen (photo. M. Harrower, 2004).

*Terraces and Hillslope Runoff (*Mudarajat *and* Shruj*)*

In highland regions of Yemen (**Figure 2**) and Oman, terraces and hillslope runoff irrigation systems employ a variety of carefully devised strategies to capture and retain soil and water in mountainous areas (Moraetis *et al.* 2020; Pietsch and Mabit 2012). These systems are only feasible in areas with some preexisting soils or sediments that are suitable, or can be made suitable, for cultivation. Terraces require substantial investments of labour for construction and continual maintenance to remain viable, but particularly if cisterns to store water are involved, they can operate even if farmers are not present to redirect rainfall.

Hillslope runoff systems are more common in areas with low-permeability bedrock, particularly in the limestone highlands of the Hadramawt (**Figure 3**) and Mahra, and less common in areas with highly fractured, highly permeable geology, including the ophiolite Al-Hajar Mountains of northern Oman. However, runoff systems

Figure 2. Terraces fed by highland springs and runoff in the valley of al-Ahjur studied by Varisco (photo. M. Harrower, 2004).

are still used in some parts of Oman, particularly where exploitation of groundwater is less feasible (Costa 1983: 287-288; Purdue *et al.* 2021).

*Wells (***Bi'r** *and* **Zajarah***)*

Wells that access groundwater (**Figure 4**) are common throughout Arabia. In northern Oman, where highly permeable geology quickly drains water beneath the ground surface after rainfall, wells have been central to oasis agriculture since the Bronze Age (Charbonnier 2014; 2017). A rich tradition of skilled labourers knowledgeable about digging wells and traditions governing the sharing of water are well-known, especially through studies of water-use in Islamic period Oman (Al-Ghafri 2008; Wilkinson 1977). Even though wells can be quite easily dug by hand in the alluvium of coastal regions of Yemen, wells appear to have been far less common in early Islamic times and irrigation from springs and wadis traditionally dominated (Varisco 2009: 392).

*Flashflood (***Sayl***)*

Systems that capture water for irrigation from flashfloods (*sayl*, pl. *suyul*) can be found throughout Southern Arabia, but are comparatively more common in Yemen (**Figure 5**) than Oman (Brunner 1997; Varisco 1983). *Sayl* irrigation requires detailed understanding of water flow and flooding after rainfall, considerable labour to construct barrages or check dams to divert water that often must be reconstructed after floods, and active management (frequently in the darkness of night) to redirect and allocate water so that secondary and tertiary canals and banked fields are properly supplied and escape damage. Enormously powerful flash floods can arrive suddenly and sadly, injuries and deaths, even with modern weather forecasting, are relatively common. The engineering, labour, and operational complexities involved in *sayl* irrigation contribute to major managerial challenges, so that particular drainages have management traditions that stretch very far back into the past and in some cases are documented by still-existing early Islamic records (Hehmeyer 2019; Varisco 1996).

*Underground Infiltration Galleries (***Qanat** *and* **Daudi Falaj***)*

Techniques for capturing water from underground aquifers, often referred to using the Persian term *qanat*, are undoubtedly the most technologically complex irrigation system used in Islamic Arabia. *Qanats* (known as *daudi aflaj* in Oman) employ a horizontal shaft connected to a series of vertical access shafts to direct water to the surface, where it is often used sequentially

Figure 3. Wadi Sana, Hadramawt, a few days after a very rare *sayl* flashflood that left water standing in the main channel. Rather than attempting to block the main flow of the wadi, ancient irrigation systems diverted water from the adjacent limestone hillslopes in the background onto arable sediments below in the foreground (photo. M. Harrower, 2004).

Figure 4. Water being drawn from a hand-dug well (*bi'r*) using a diesel pump in Ghayl Bin Yumain, Hadramawt, Yemen (photo. M. Harrower, 2005).

Figure 5. Dam slowing water from *sayl* flashfloods in Ghayl Bin Yumain, Hadramawt, Yemen (photo. M. Harrower, 2005).

for religious purposes, domestic cooking and washing, irrigating crops, and watering animals. Considering their widespread occurrence and advanced technical sophistication in Iran, *qanats* have long been thought to have originated in ancient Persia (Lightfoot 2000a). In addition to their modern prevalence, the contention that *qanat* technology originated in Iran has also been frequently supported by reference to a cuneiform text of 714 BCE detailing the 8th campaign of Assyrian King Sargon II against Urartu that supposedly describes *qanat* technology. However, this oft-repeated reference as supposed proof of *qanats*' early presence has been strongly questioned, as most have relied on secondary sources and the original cuneiform text describes water management but not necessarily *qanats* (Hehmeyer 2019: 193-195; Salvini 2001). Based on careful archaeological investigation and radiometric dating, current evidence indicates that the earliest confirmed use underground infiltration gallery technology is found during the 1st millennium BCE in the UAE (Magee 2007: 86-90) at Hili and Bida Bint Sa'ud (Al-Tikriti 2002; 2011) as well as in the Al-Madam area (del Cerro and Córdoba 2018).

Despite a long history of connections with eastern Arabia and Iran, relatively few *qanats* are found in Yemen. Lightfoot attributes this relative absence to Yemen's unique 'ecology of place and inertia of tradition' (Lightfoot 2000b: 2). Indeed, it is important to note that *qanat* technology is only suitable in certain geological settings, and techniques vary substantially in different regions according to the legacy of water management practices. Hehmeyer (2019: 189-195) argues that water capture from karst geology at Ghayl Ba Wasir, Hadramawt (one of the most studied *qanat*-like systems in Yemen) was devised independently of Persian inspiration, but it is difficult to completely exclude foreign influences given that *qanats* and *daudi falaj* systems appear far earlier in Iran and UAE than dates estimated for Yemen.

Other water-related infrastructure

In addition to the aforementioned water management technologies there are some other less-commonplace but nevertheless important constructions related to water in Southern Arabia. These include infrastructure for water capture and storage, such as the Cisterns of Tawila (also known as the Tawila Tanks) near Aden in Yemen. This system historically consisted of water diversion structures and over 50 water storage tanks that formerly captured and stored up to 19 million gallons of water from Wadi Tawila (Norris and Penhey

Figure 6. The Shaharah Bridge, Yemen (photo. Bernard Gagnon, Wikimedia, https://commons.wikimedia.org/wiki/File:Shaharah_bridge.jpg).

1955). These tanks served the dual purpose of mitigating the risk of flooding and supplying water to the city of Aden. Although they were reconstructed during the British occupation of Aden, their original time of construction is not entirely clear. Norris and Penhey (1955) claim a version of the tanks may have existed as early as the Himyarite era, and the cisterns appear to have been mentioned by Islamic scholars. However, the precise details of the systems' operation during Islamic times remain complex and uncertain (Serjeant 1957).

Also in Yemen, engineering expertise developed in constructing water management systems contributed to skills needed for building roads and bridges that could withstand powerful water flows in rugged terrain and deep canyons. One prominent example, the Shaharah Bridge constructed in the 17th century is still standing and attests to advanced skills in design and engineering (**Figure 6**).

In Oman, a variety of other water-related technologies are noteworthy, including water-driven mills for grinding grain and inverted siphons (*gharrāq-fallāh*) used to transport water in canals across gullies (Costa 1983: 280-285). The first invention of watermills, among the world's earliest machines, remains a matter of considerable uncertainty, but perhaps the earliest examples are to be found in the eastern Mediterranean during the last few centuries BCE (Wikander 2000: 394-397). Similarly, the earliest known use of an inverted siphon is at Zincirli in southeast Turkey (Naumann 1955: 184-185; Wikander 2000: 619), so the technology is not demonstrably invented in Arabia but certainly was adopted and adapted to local circumstances in Southern Arabia in creative ways (Costa and Wilkinson 1987).

Islamic Water Law and Tribal Customs

Water plays a deeply important role in Islamic Law (Amini 2022, Yasrebi 2022, Ahmad 1999). Indeed, the term *sharia,* which denotes Islamic law, is sometimes taken to mean path to follow or path to watering place (Weiss 1998: 17). Core elements of *sharia* pertaining to water are designed to prevent overexploitation, monopolization, and guide responsible use of water (Wilkinson 1978: 88). One of the most central principles of Islamic law pertaining to water, is the precept that naturally flowing water is communal property and must be made freely available to all (Naff 2009). This right to access water to quench the thirst of humans and animals whether in its natural or human-made course, supersedes all other regulations in that every human and animal has the right to access water for drinking, provided they do not pollute the water or alter its course (Wilkinson 1990: 60).

In relation to the general principle of equity, one of the more complicated aspects of Islamic *sharia* pertaining to water is that it can be interpreted and customized according to local traditions and circumstances while adhering to the spirit of the original guidelines (Wilkinson 1978: 89). The principle of free access becomes complicated and subject to exceptions in practice as those investing in capturing or improving water resources must have some way to secure rights to the proceeds of their investments. For instance, natural land is considered to only be vivified by water (The Qur'an, 36: 33, 43: 11, 50: 11) and rights to vivified land are to be granted to the first person who revitalized it (Wilkinson 2010: 306). Similarly, in many Islamic contexts, if a person or group invests capital or labour in harnessing water, such as by building a dam or digging a canal or a well, they do gain exclusionary rights to the water captured; a necessary precondition that very likely has pre-Islamic origins (Harrower 2016: 16).

In light of these general principles, Islamic *fiqh* (jurisprudence) and daily practices developed in Southern Arabia over many centuries in concert with specific hydrological and social circumstances, and tribal customs. Some of our most detailed records of early Islamic water law come from Oman, where Ibadi rule was established during the middle of the 8th century (al-Rawas 1990) and the new rulers inherited pre-existing *falaj* water management systems (Wilkinson 2002). One initial challenge was adapting existing irrigation systems, concepts of territory, (Wilkinson 1983), and the needs of tribal communities while adhering to Islamic and Ibadi frameworks (Wilkinson 1978: 90). Correspondingly, in Yemen, in 820, the Abbasid Caliph in Baghdad (al-Ma'mūn) sent Muhammad ibn Abdallah Ibn Ziyād to the Tihama region to resolve conflicts with local tribes and Ibn Ziyād founded what eventually became the historically important city of Zabid along Wadi Zabid (Hehmeyer 2019: 61-63). The Ziyadid Dynasty was thus founded at Zabid in the area that was previously only a village (al-Husayb). Irrigation systems focused on capturing water from *sayl* flashfloods and baseflows of Wadi Zabid and its tributaries, generating many centuries of experience with engineering technologies and legal frameworks governing water rights, allocation, and taxation of agricultural production (Hehmeyer 2019: 59-153).

In terms of water sharing and allocation, a variety of different traditions are known across the Islamic World, with specific variants prevailing in southern Arabia. Traditions include allocating water by land area, by water volume, or by intervals of time, with adjustments made according to the quantity of water available during floods and/or at certain times of year. Allocations based on time were often managed by time shares, which were measured using either observations of Sidereal time or mechanical devices such as water and sand clocks. These methods were sometimes combined within the same irrigation system (Wilkinson 1978: 93). In some polities, it required the intervention of the central authority to act as both a mediator between conflicting interests and an administrator, the best exemplification is the water division system of Zayandeh Rud basin first regulated by Sasanian emperor Ardashir I (180-242) then endorsed by the Muslim conquerors and expanded upon by Sheikh Baha'i (1547–1621) the reformist chancellor of the revivalist Safavid Dynasty (Khaneiki 2020: 45). This was not the case for Early Islamic Oman, where the settled Arab tribes realized that their inherited irrigation system was in decay (Simonen 2021: 78, Wilkinson 1983: 66). Soon after the reestablishment of the Ibadi Imamate in 793, the need for a legal framework, maintenance and upkeep of the *aflaj* was realized (Dybro, 1995; Simonen, 2021: 81-102) through a series of comprehensive jurisprudence rulings described by Jami Ibn Ja'far (al-Izkawi 2018: IV:XI) and Jami Abi al-Hawari (Ibn al-Hawari 1985: II: XXIX) and early Imams' political maneuvers and interventions (*Tuhfah I: 125-126, 128-129).*

Two fundamental tenets guided the irrigation rulings in the Ibadi ethos: fair dealings and communality of interest. The objective was to ensure the unity and survival of the villages centered around the *aflaj* networks (Wilkinson 1978). To incorporate these principles, some deviation from Islamic *fiqh* was inevitable. For instance, in Ḥanbali *fiqh,* upstream exploiters have almost no obligations toward the downstream users, except for the general guideline set by the Prophet regarding the amount of water to be taken - one ankle's depth (Wilkinson 1983: 61). While this might have been appropriate for surface water exploitation and flash flood management in western Arabia, which was the Prophet's home, it was not suitable for the Omani agricultural political economy based on consensus and mass participation in projects of groundwater exploitation, that is, building and upkeep of *aflaj* (Wilkinson 2010: 306). In the latter context, the focus was on outlining the rights and obligations of each shareholder concerning matters such as changes in water flow, minor repairs, and ongoing maintenance, including the reinforcement of channels and adjustments to the irrigation schedule to maintain the cohesiveness and harmony of the water-sharing community (Wilkinson 1983: 66). An anecdote that exemplifies the customization of Ibadi guidelines while adhering to the Islamic principles (*usul)*, concerns the right to upkeep an irrigation channel passing through a settlement *harim* (boundary) and tribal land (Wilkinson 2010: 261). When the issue first arose under Imam Ghassan (808-823) he navigated the public consensus toward the view that no land tenure shall prevent access for repair and maintenance of a *qanat* or *falaj* passing on or under the *harim* of a settlement or tribal land (Wilkinson 2010: 306).

The Political Organization of Water Management

It might be self-evident that sociopolitical structures impact irrigation management systems, especially in communities residing in arid and semi-arid regions where water supply is the thin lifeline of agricultural settlements. However, the influence of established water management practices and inherited irrigation systems in the establishment of a new socio-political order after periods of societal upheaval is often underestimated. We have discussed the intricacies of the sociopolitical system in the newly formed Early Islamic society of Oman elsewhere (Zaribaf *et al.* 2024). However, it is perhaps more appropriate to discuss here how the *aflaj* inheritance of Omanis influenced the shaping of the sociopolitical structure and political economy of Islamic communities.

Before delving deeper into details of how *falaj* management apparatus influenced the decision-making process in the first Ibadi imamates it is necessary to discuss those arrangements that probably took root in the pre-Islamic traditions in more detail. First it must be acknowledged that despite drawing on the same Islamic and Ibadi jurisprudence foundations discussed earlier, almost every hydrological community and village has its own unique irrigation organization and even distinctive terminology (Simonen, 2021: 102; Wilkinson, 1977: 97). However, here we only address the most conventional methods and employ the most common terms in Oman. In the Islamic era the more substantial *aflaj* had a communal organization responsible for its maintenance and distribution of water among shareholders (Ubaydli 1993). Which judging from the linguistic evidence and the earliest Ibadi jurisprudence rulings referring to an already pre-existing system among the non-Muslims, could have roots in the pre-Islamic traditions (Wilkinson 2010: 305-318). The water shareholding system by which the water was supplied to various shareholders or users at specific times in accordance with a predetermined consensual rotating schedule called *dawran*, which literally translates to rotation (Ubaydli 1990). After the construction of the *falaj* a committee of experts is assembled by the farmers to determine the length of the irrigation cycle (*dawran)* and the shares of each stakeholder based on the number of owners, their proportional contribution, flow rate, water flow fluctuations, soil type, amongst other factors (Al-Ghafri, 2004). The total length of *dawran* is said to be usually between 7-14 days; however, cases have been reported to be as short as 4 days and as long as 20 days (Al-Ghafri *et al.*, 2003: 3). The most common length of a share (*khabûra)* is 24 hours, which is divided into two 12-hour *bada.* The other common time units employed in water shareholding are *athar or suds* roughly half an hour.

Wilkinson (1977:108) mentions smaller share units; however, he notes that they are byproducts of the complex Islamic inheritance laws and are rarely used as measurement units. In practice, the lesser number of shares and shorter irrigation cycles allowed for more efficient use of land and water and better adherence to the principle of equal shareholding (Simonen, 2021: 105). Time units are either measured by celestial movements, such as the length of a person's shadow during the day or the movement of the stars during the night or by basic water timers called *tasa* (Al-Ghafri, 2004: 54; Wilkinson, 1977: 109-110). Every village in Oman was self-sufficient, thus most irrigation channel maintenance, especially on the smaller channels which lay within the responsibility of each landowner. However coordination of communal work on the primary falaj (italics) channels, and the occasional employment of outside expertise necessitate collective organization (Bandyopadhyay *et al.*, 2013; Simonen, 2021; Ubaydli, 1993; Wilkinson, 2010).

At the top of the *falaj* organization sits the appointed *wakil* (agent) who coordinates the auctioning of *falaj* shares and maintenance of the above-ground and underground channels. On the other end, there are the workers (*bayadir)* who undertake the actual work. Depending on the size and importance of the *falaj*, other officials may be employed, including: '*arîfs*, responsible for fair and timely distribution of each water share, *basir* and *awamir* hydrological experts contracted and consulted on situational basis, *qabidh*, the treasurer, *dallal*, the auctioneer responsible for auctioneering the *falaj* share, *amin al-daftar*, the bookkeeper, and *munadi,* the crier (Al-Ghafri, 2004; Al-Marshudi, 2007; Simonen, 2021; Ubaydli, 1993; Wilkinson, 1977). The main financial instrument behind the creation of the local *aflaj* communal management system is the Islamic principle of *waqf (pl. wuquf),* in which a property in its entirety or partially becomes an indefinitely inalienable tenure whose proceeds could only be used for specific purposes mentioned in the *waqfname/ waqfiya* (the deed document). The water shares of a *falaj* as discussed earlier fully satisfy the conditions of a property that could be subject to *waqf* (Wilkinson 1977: 113). In some *aflaj* there are also shares reserved for the Islamic government under the umbrella term *bait al-mal* (Al-Ghafri, 2004: 49). The shares that belong to the *falaj* organization, depending on their legal standing could be categorized as the original *qa'adah,* the shares under *waqf* and *zayida* shares which are added on an ad-hoc basis to meet temporary needs of the *falaj* and could be sold in an auction to raise money (Wilkinson, 2010: 317, 1977: 114). Conversely, there could be other *wuquf* whose deeds and proceeds do not directly concern the upkeep of the *falaj* but are directed toward other charitable objectives such as education and religious public services (Al-Ghafri, 2004; Khaneiki *et al.*, 2024). The decentralized nature of this system which was established in the aftermath of a great social upheaval during the second half of the eighth century CE continued to contribute to the prosperity of Omani agricultural society throughout the Islamic era and was even strengthened by the reformation and easement of Ibadi land and property legal framework under the Ya'rubid Imamate from 1624 to 1742 (Bandyopadhyay and Mershen, 2022: 41). Having examined all the elements above, we can envisage how the hydrological independence and socio-political uniqueness of Omani agricultural communities have paved the way for a decentralized form of governance based on the principals of participation, mutual agreement and fairness indoctrinated in the Ibadi ethos.

Conclusions - Lessons from the Past

There are a variety of important lessons to be learned from the Islamic era history and archaeology of water management and irrigation in Southern Arabia, including recognizing the importance of climate change, valuing cultural and agricultural heritage, and promoting long-term sustainability and conservation.

Given the impressive legacy of water control systems, it is tempting to call for technologies of the past, such as terracing, runoff irrigation, and *qanats*, to be revived and reintroduced in Yemen and Oman. In cases where such systems still survive, it is deeply important to study and preserve them both in terms of technology and social history, and some may be suitable for reconstruction (Al-Hebshi 2019). In modern times, traditional systems are valuable for agricultural production, historic preservation, and heritage tourism. However, current populations' demands for food and water far exceed the quantities that can be supplied by traditional water management and local agricultural production; imported food is a major component of the food supply in both Oman (Al-Busaidi and Jukes 2015) and Yemen (Thomas 2022). Particularly over the past few decades, neoliberal economic policies have left local farmers struggling to compete with highly competitive international markets in which inexpensive food can be imported, but local food security, human dignity, and independence also need to be valued beyond an exclusive and myopic focus on international macroeconomics (Basha 2023). Even so, traditional systems are unable to meet the demands of far larger modern populations, and technologies including desalination are to some extent unavoidable (Al-Jabri *et al.* 2015).

Despite the complications of modern economics and population growth, Islamic history and traditions offer critical social, political, and ethical lessons that are pivotal in addressing crises related to water in the present and the future. First and foremost, Islam requires equitable access to water and prohibits overconsumption and pollution of water. Traditional water management technologies and practices outlined above, including terraces, runoff, floodwater, and infiltration gallery techniques, should be preserved and revived not only because of their inherent sustainability but also for eco-tourism and to educate current and future generations in ways that emphasize the importance of heritage and environmental conservation.

In the contemporary world of climate change, water crises and drought will undoubtedly become increasingly critical concerns. Emphasizing the very sensible stipulations of early Islamic customs can be a powerful tool to promote sound water management practices. Heritage can also be instrumental in building knowledge of long-term histories in which climate change was demonstrably impactful and mutual understanding constructed on knowledge of history can be a forceful basis to identify common ground and shared values that are essential to addressing conflict and building cooperation in the present.

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Chapter 4.
Water Management at Qurḥ/al-Mabiyāt (North-West Arabia): Between the Exploitation of Natural Resources and the Mitigation of Risks

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Introduction

Location

The site of al-Mabiyāt, identified with the historic city of Qurḥ (Nasif 1979), a major urban centre in the Hejaz, is located c. 19km south-east of the modern town of AlUla (al-ʿUlā), Saudi Arabia (**Figure 1**), and north-west of the village Mughayra and its palm groves. It lies on the north-eastern edge of a wide wādī basin and is close to the confluence of several smaller wādīs coming from the mountains to the north. The site lies at the crossroads of the reconstructed ancient trade routes of the Arabian communication network (Durand 2019; Frenkel 1996: 181; Young 2011: 90–135; Fiema *et al.* 2020a; 2020b). These routes subsequently became important for the pilgrimage from Syria and the Levant to the Islamic holy sites of Makkah and Madinah (Al-Kilabi 2010; Gilmore *et al.* 1985; Petersen 2012: 9–16, 29–37, 148, 153; Al-Ghabban 2019). Univocally, the

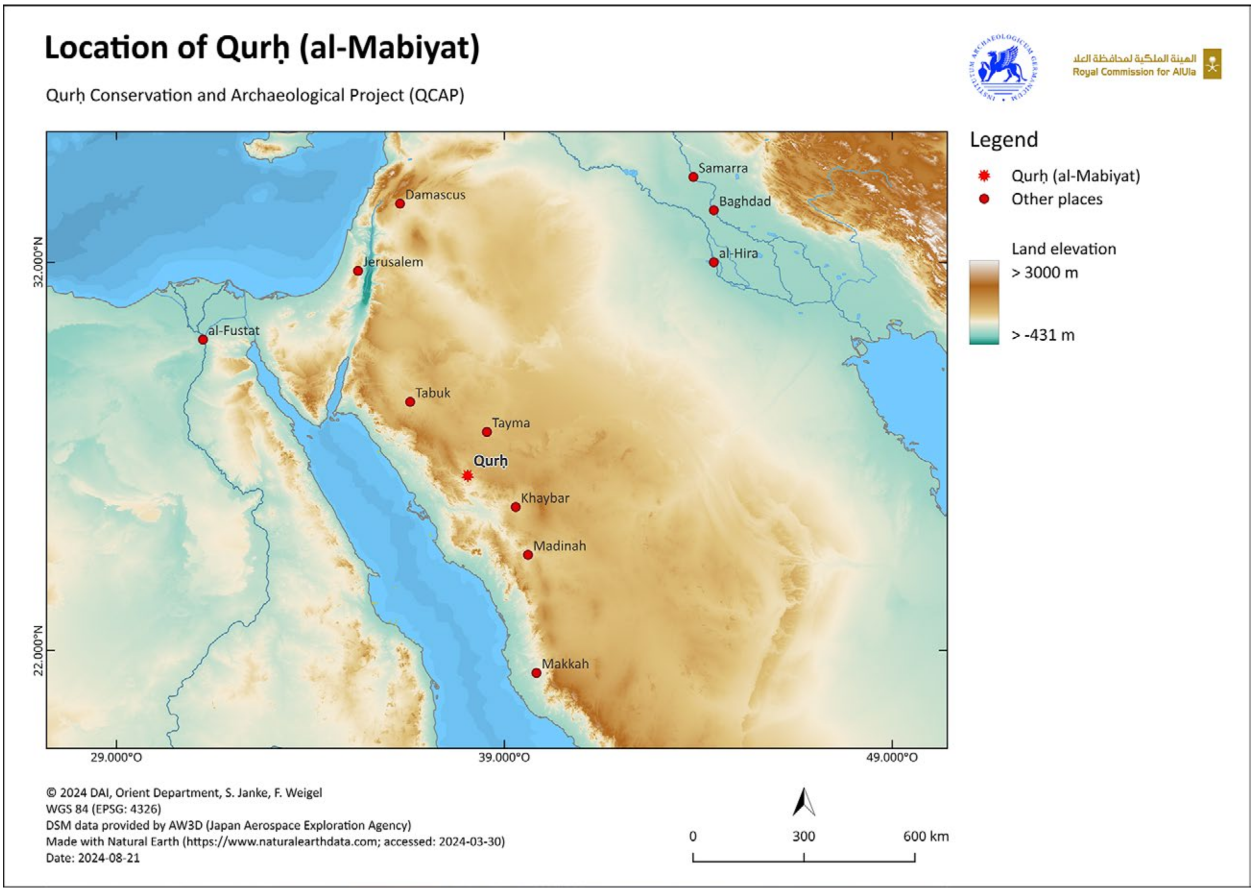

Figure 1. Location of Qurḥ in the Hejaz (north-west Arabia, © DAI, Orient Department, S. Janke / F. Weigel).

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historical sources report that the city had a major market, providing economic wealth and producing goods as well as had far-flung contacts to Iraq, Syria and Egypt which is also reflected in the material culture of the site, including imports from as far away as China (Gilmore *et al.* 1985: 116; Al-Muaikel 2011: 57, pl. 3.12c; Al-Aboudi 2019: 37).

Previous research

Early travelling scholars, such as C.M. Doughty (1921: 161–162)[1] or A. Jaussen and R. Savignac (1914: 26) mentioned the site of al-Mabiyāt, but did not visit it. Peter Parr and colleagues briefly surveyed al-Mabiyāt and its environs in 1968 and described it with high probability as an '*Umayyad foundation*' and an important mediaeval city (Parr *et al.* 1970: 201). The 'Comprehensive Survey of the Department of Antiquities' listed Qurḥ / al-Mabiyāt as site no. 204-43, whereas remains of a separate Qal'a were recorded as no. 204-44 (Ingraham *et al.* 1981: 79).

The first archaeological excavations started with two seasons in 1984 and 1985 under the auspices of the then Department of Antiquities (DA; Gilmore *et al.* 1985: 109; Al-Talhi *et al.* 1986). One of the main objectives was the establishment of a pottery sequence for dating the archaeological deposits in the context of the textual sources as well as to compare the ceramic and architectural traditions in the Hijaz with those of Egypt during the Tulunid and Fatimid periods. In fact, the early excavators recognized striking similarities between the written accounts of Qurḥ and the actual topography of the site of al-Mabiyāt (Gilmore *et al.* 1985: 110–111). Furthermore, the date of the pottery corresponded with those periods covered by the historical accounts on Qurḥ and Wādī al-Qurā (Parr *et al.* 1970: 201; Gilmore *et al.* 1985: 117–121; Al-Talhi *et al.* 1986: 62–63; Al-Muaikel 2011: 54–58). However, Al-Omeer (2006: 131) noted the absence of any evidence for the early Umayyad period on the site.

An expedition from King Saud University, Riyadh, continued excavations at the site in 2004. Until 2019, an area within the city wall, close to the northern edge of the enclosure, was excavated annually (Al-Omeer *et al.* 2006; Al-Muaikel *et al.* 2011; Al-Ghazzi *et al.* 2018; Al-Aboudi *et al.* 2019; cf. Al-Aboudi 2019; Al-Aboudi 2021). Since 2022, the DAI-RCU Qurḥ Conservation and Archaeological Project (QCAP) has been conducting research at the site of Qurḥ.[2]

Historical sources

Historical accounts (cf. Al-Wohaibi 1969; Gilmore *et al.* 1985; Nasif 1988: 111–113) ascribe a significant role to Wādī al-Qurā at the time of the Prophet Mohammed and Caliph Umar ibn al-Khattab, when the Jewish communities in the region formed a defensive alliance. After the fall of Wādī al-Qurā and Khaybar, the former fell under the administrative control of Madinah. Whereas the Jewish communities were eventually expelled from the region by Umar ibn Abdul-Aziz in the early 8th century CE (all dates are CE unless otherwise specified), Al-Muqadassi (1897: 132 [84]) mentions a substantial community in Qurḥ in the 10th century. The accounts provide information on the changing fortunes of the economic situation of the region during the Umayyad period. In the 9th/10th century, reports of Qurḥ's prosperity refer to trade links and the exploitation of resources (Al-Wohaibi 1969; Kisnawi *et al.* 1983; Power 2010: 185–188). A detailed description of Qurḥ is owed to Al-Muqadassi (1897: 132–133 [83–84]):

> *'The town of Qurḥ is the largest in al-Ḥijaz at the present Day after Makkah, as well as the most flourishing and populous, and the most abounding with merchants, commerce and riches. It is commanded by an impregnable fortress, at an angle of which a castle arises. Villages encircle it on all sides and palm trees skirt it about; and, besides, it is possessed of very cheap dates and excellent bread and copious springs of water, pretty houses and busy markets. The town is surrounded by a ditch and has three gates covered with iron plates. The mosque is in the midst of the main streets of the town [...] In fine it is a Syrian, an Egyptian, an Iraqian and a Ḥijazite town all in one, but the water is unwholesome and its dates of middling quality. The public bath is outside the town. Qurḥ is chiefly inhabited by Jews. [...] Al-Aunid is the port of Qurḥ, a prosperous town having plenty of honey and a good anchorage.'* (Al-Muqadassi 1897: 133–134 [83–84])

Accordingly, water seems to have been available in large quantities, but its quality has been described as '*unwholesome*' and even '*bad*' (Al-Muqadassi 1897: 134 [84], 152 [101]). The quality of the water may have been implicitly taken as an explanation for '*its dates of middling quality*' (Al-Muqadassi 1897: 134 [84]). Therefore, water management may have been an even more important factor for the sustenance of the thriving city of Qurḥ. The economic well-being of Qurḥ

[1] Doughty asked locals about Qurḥ, but its identity with the ruins of al-Mabiyāt seems to have been unknown at that time.

[2] The project is carried out by the Orient Department of the German Archaeological Institute (DAI). It is headed and directed by Arnulf Hausleiter, while Friedrich Weigel (both DAI) is the local field director. The hydrological research unit is led by Patrick Keilholz, while Anna Nilges (both Technical University of Applied Science, Nuremberg) investigated the modern and historical catchment of the site. Funding has been provided by the Royal Commission for Al-ʿUlā (RCU). The authors are indebted to Stefanie Janke, Eva Schmalenberger and Julius Kardaetz (all DAI) for data creation and processing. The heads of the conservation unit, Katharina Kuntz, and of the archaeological survey unit, Ulrike Siegel provided valuable information, as did Mustafa Ahmad (pottery analysis) and Stefano Aprà (all DAI), while Rebecca Foote and Wissam Khalil of RCU offered strategic and logistical support.

Figure 2. View of abandoned palm gardens south-east of al-Mabiyāt (© DAI, Orient Department, F. Weigel).

seems to decline during the Fatimid period, although until the Ayyubids a settlement, apparently on reduced scale, is reported. At the end of the twelfth century the site had apparently been abandoned with no one using the water available there (Al-Yaqut; Wüstenfeld 1869: 54, 81, cf. Power 2010: 190).

Water management: general patterns, now and then

The provisioning of water in the Al-ʿUlā region was traditionally undertaken through the utilisation of a range of water sources and storage facilities, including wells, cisterns, basins, and *qanat*s. These were employed in conjunction with natural springs, underground aquifers, and surface run-off (cf. Nasif 1980; Dayton 1975: pl. 2, 4). The introduction of diesel pumps, especially during the 1970s, enabled the accessibility of lower-lying water reservoirs, facilitating the intensive extraction of fossil waters for the development and expansion of agricultural areas and their yields. This resulted in a reduction of the size of the reservoirs, the drying up of springs and a reduction in groundwater levels, rendering the old *qanat* systems inoperable. Furthermore, a significant flood event in 1972 destroyed or blocked numerous underground structures in Al-ʿUlā (Nasif 1980: 76; Nasif 1988: 162, 167–168). Together with the population growth of Al-ʿUlā and Mughayrah and the expansion of agricultural areas since the mid-twentieth century (Battesti 2023[3]), a self-reinforcing cycle of land and resource overexploitation may have been set in motion (Nasif 1988: 171; cf. Al-Kolibi 2002; Al-Otaibi *et al.* 2023; Suhail *et al.* 2024). Although thunderstorms with heavy precipitation are not uncommon, their risk impact is amplified when concentrated in a single event, particularly when compared to the same amount of rainfall distributed evenly throughout the year.[4] However, the utilisation of precipitation served to supplement the utilisation of groundwater and its recharging. The climate appears to have become drier than it was in historical periods, as evidenced by the presence of abandoned agricultural areas (Dayton 1975: fig. 4). The remaining palm gardens near al-Mabiyāt are currently irrigated by pumping water from Mughayrah, as the water table has continued to decline. However, many of these gardens have already been abandoned (**Figure 2**). Another challenge evident in the agricultural area south of al-Mabiyāt is salinisation, which is closely linked to the availability, quantity and utilisation of water (e.g. insufficient draining; Parr *et al.* 1970: 199; Dayton 1975: 46, 48, pl. 3; Nasif 1988: pl. CLXXVa).

[3] This resource provides a comparison of satellite imagery of the area of Mughayrah between 1972 and 2023, cf. Battesti 2023. Whereas in 1972, many plots of land have been already delimited, the area seems to have been cultivated only scantily. As for today, cultivated and abandoned farms cover an area of *c.* 938ha until reaching the village of Mughayrah. However, not all plots of land seem to have been cultivated at the same time as indicated by the satellite images. Currently, an area of *c.* 444ha (47% of the whole area) is under cultivation.

[4] For reference, mean climatic charts for the region based on data between 1986 and 2001 can be found in Al-Zahrani 2009: 85, fig. 6–7.

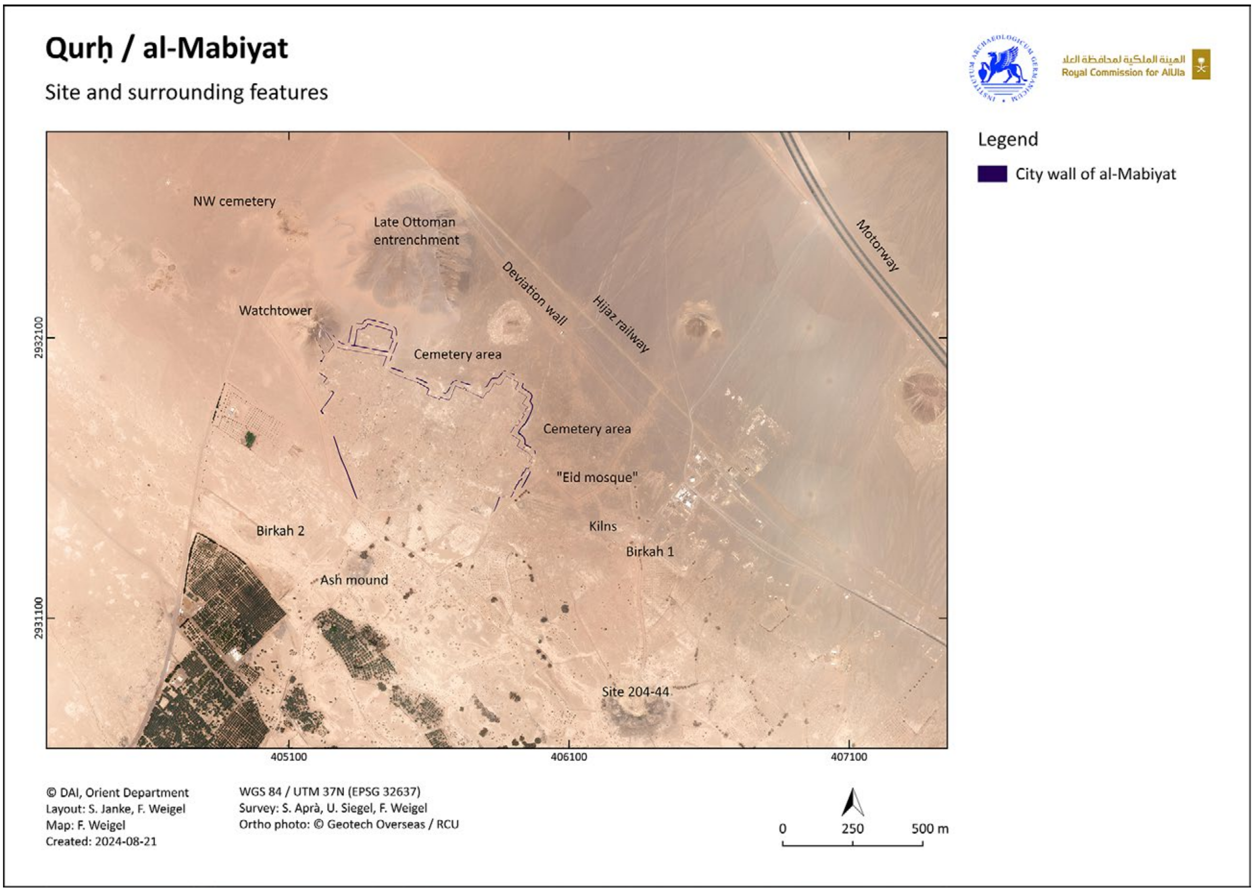

Figure 3. Features in the surrounding of Qurḥ / al-Mabiyāt, including hydraulic structures (© DAI, Orient Department, F. Weigel).

The site and its surroundings

The site of al-Mabiyāt is located within a larger basin between the red sandstone formation in the north, extending from the north-west to the south-east, and the parallel basalt formations in the south (Ḥarrat al-ʿUwayriḍ; cf. Al-Zahrani 2009: 84, fig. 2–5 with further references). According to Dayton (1975: 46, fig. 4; also cf. Parr *et al.* 1970: 199) the basin has its lowest point near Badaʿi, approximately 3.5km south of the site, where the basin is drained by Wādī Mughayrah. The water gathers in the plain south of al-Mabiyāt from different directions (Wādī al-ʿUlā with Wādī Ramm from north-west, Wādī Nakhlah from north-east and several smaller wādīs from north). The general gradient of the site declines steadily from north towards south-east, whereas the topography of the surroundings follows the main wādī course, declining from north-west towards south-east.

The area enclosed by the city wall, as much as it has survived, covers approximately 35ha. The fenced area of the protected archaeological site extends to 100ha, but the archaeological remains are distributed far beyond its limits, particularly to the east, south, and north-west of the site. The southern extent of the city is no longer recognisable due to the bulldozing of the area for preparing the terrain for the cultivation of palm trees[5] (**Figure 3**).

Stratigraphy and occupation history

Archaeological open area excavations conducted across the site in 2022 and 2023 in Areas A, B, C, CW, and F (**Figure 4**), combined with the analysis of the pottery and recent radiocarbon dates show that the most expansive phase of Qurḥ can be dated to between the 9th and 11th centuries. Thereafter, the settlement has been apparently abandoned during the 12th century. Whereas chronostratigraphic soundings in Areas A, F and G bear evidence for considerable building dynamics within this relatively short occupation period, the architecture was founded on a layer of aeolian sand

[5] This must have occurred prior to 1968 (cf. Parr *et al.* 1970: fig. 2 and according to another of Parr's drawing from this visit (RCU.2019.21.6_RCU004, thanks to Jonathan Wilson from RCU Collections for sharing a digital copy).

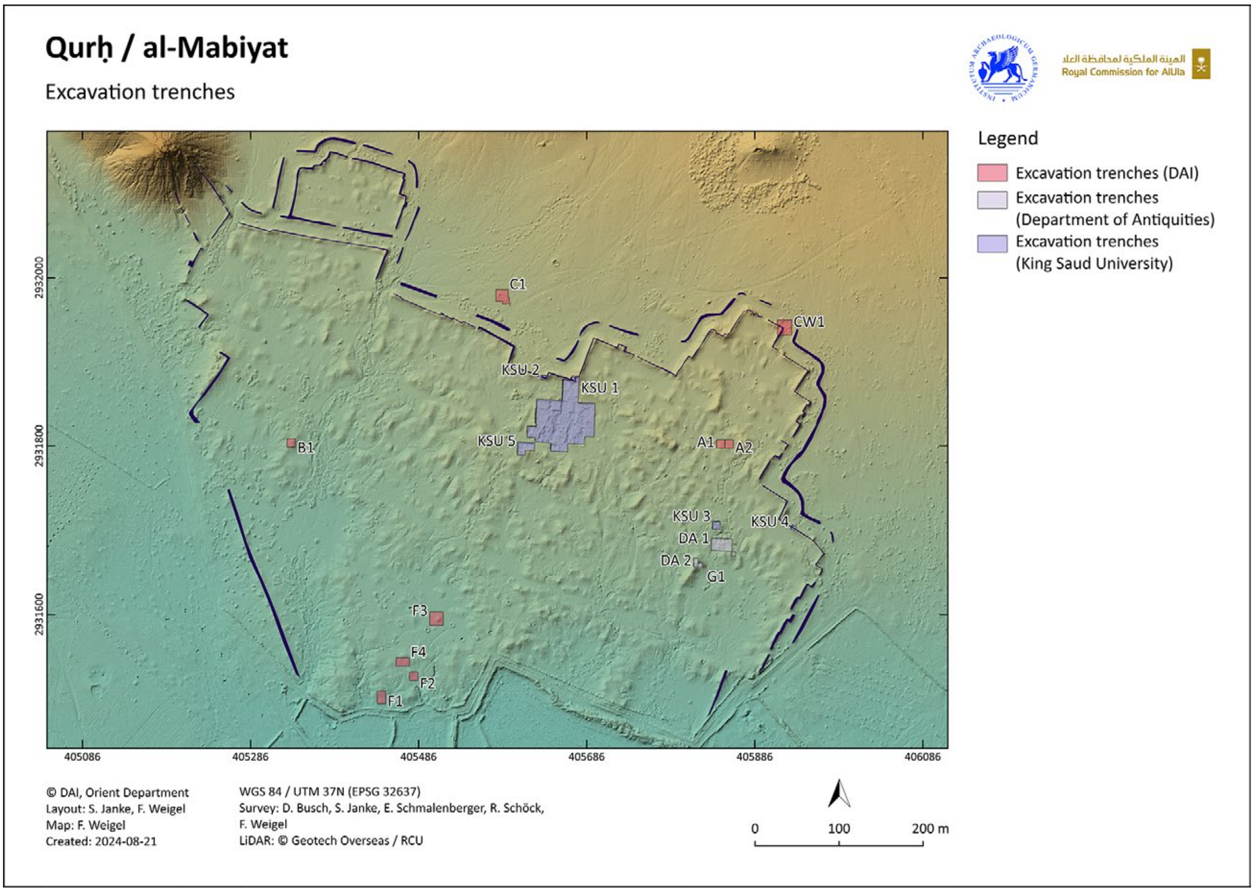

Figure 4. Map of old and new excavation areas in Qurḥ / al-Mabiyāt (© DAI, Orient Department, F. Weigel).

devoid of anthropogenic materials (soundings in Area A and G) or alluvial deposits (Area F).

However, there is evidence for an earlier occupation at Qurḥ, as suggested by stray finds and spoils. A newly discovered Dadanitic inscription mentioning the Nabataean king Obodas II. dated to the year 27 BCE (reading kindly provided by F. Kootstra),[6] as well as pre-Islamic remains at a nearby outlier (site no. 204-44, Gilmore *et al.* 1985: 112) call for an integration into a general occupation history of Qurḥ / al-Mabiyāt. Earlier, 'a strong possibility that Maʿabiyat is an Umayyad foundation' had been postulated (Parr *et al.* 1970: 201), while a supposed continuity from Late Antiquity to the 11th century was put forward subsequently (Gilmore *et al.* 1985: 118–121). However, none of these hypotheses has been confirmed by the chronostratigraphic sequence or the associated stratified pottery, so far.[7] Therefore, it seems possible that an older settlement was either located elsewhere and shifted to the area occupied in the 9th – 11th centuries, or a core settlement of limited extent expanded from a yet unknown location within the walled area of Qurḥ. If this holds true, the 9th to 11th century occupation of al-Mabiyāt (the Qurḥ described by Al-Muqaddasi) may represent a sudden expansion or (re-)foundation of the city rather than the result of a gradual growing process.

Surface run-off as risk and its management: today

The al-ʿUlā region is characterised by an arid climate and experiences limited precipitation, with annual rainfall concentrated in a few events. During periods of heavy precipitation, there is minimal water retention due to the scarce vegetation. The situation in al-Mabiyāt is further exacerbated by its location at the foot of an alluvial fan from a lateral valley. The steep topography of the catchment area serves to accelerate the rate of run-off, resulting in flash floods that are a common occurrence in these arid landscapes. The inherent danger of flash floods is derived from two primary factors: the rapid current and the substantial sediment load they carry. These floods pose a significant

[6] Similarly, a funerary Nabataean-Aramaic inscription, dated to CE 280, was found reused in a column base (Al-Muaikel 2011: 59–60, pl. 3.7c, 3.15d).

[7] The new excavations could not confirm the findings and conclusions provided by Gilmore *et al.* 1985: 118–121. Any pre-tenth-century pottery, observed in extremely limited quantities, is associated with 10th / 11th century pottery even in the oldest excavated building level (information kindly provided by Mustafa Ahmad).

risk to human settlements situated in the vicinity of these wādīs, making them among the most destructive natural disasters in the region (cf. Shi 2014; Elsebaie *et al.* 2023; Shah *et al.* 2023).

Heritage at risk

The architectural remains at al-Mabiyāt are predominantly composed of adobe, a material susceptible to erosion by wind, water, and the changing extreme temperatures. Consequently, the threat of flooding represents a significant risk to the preservation of this cultural heritage, as evidenced by the visible impact of past flooding events and the resulting damage to the archaeological remains of the site. A recent precipitation event occurred on 7 February 2019, with a total of 49mm of precipitation recorded within a two-hour period. The resulting surface run-off breached the city wall in the north and deposited a considerable quantity of sediments within the nearby excavation trenches of the King Saud University (KSU1 and 5; Nilges *et al.* 2024: fig. 2), causing significant damage to the exposed architectural remains (Castelli 2021; Margottini *et al.* 2022). In light of these conditions, all trenches of the former excavations have been backfilled, and all new excavation trenches have been backfilled at the conclusion of each season, with the objective of ensuring the optimal preservation of the archaeological record.

The flash flood risks currently facing the archaeological site prompt the question of why this area was chosen for settlement in the first place. Therefore, a model of the historic situation was developed to enable the assessment of the inevitable surface run-off and potential solutions during the period of Qurḥ's major occupation period.

Modelling the catchment and flood protection measures

The present-day catchment of the site was delineated using a catchment delineation tool (MIKE HYDRO software) and a digital terrain model (DEM). The catchment area extends to the north-east of the fenced archaeological site along a side valley and encompasses an area of 14.8km². The size and extent of the delineated catchment closely matches the catchment area determined by Margottini *et al.* 2022 using runoff accumulation methods. The catchment is highly affected by modern infrastructure as it is crossed by the

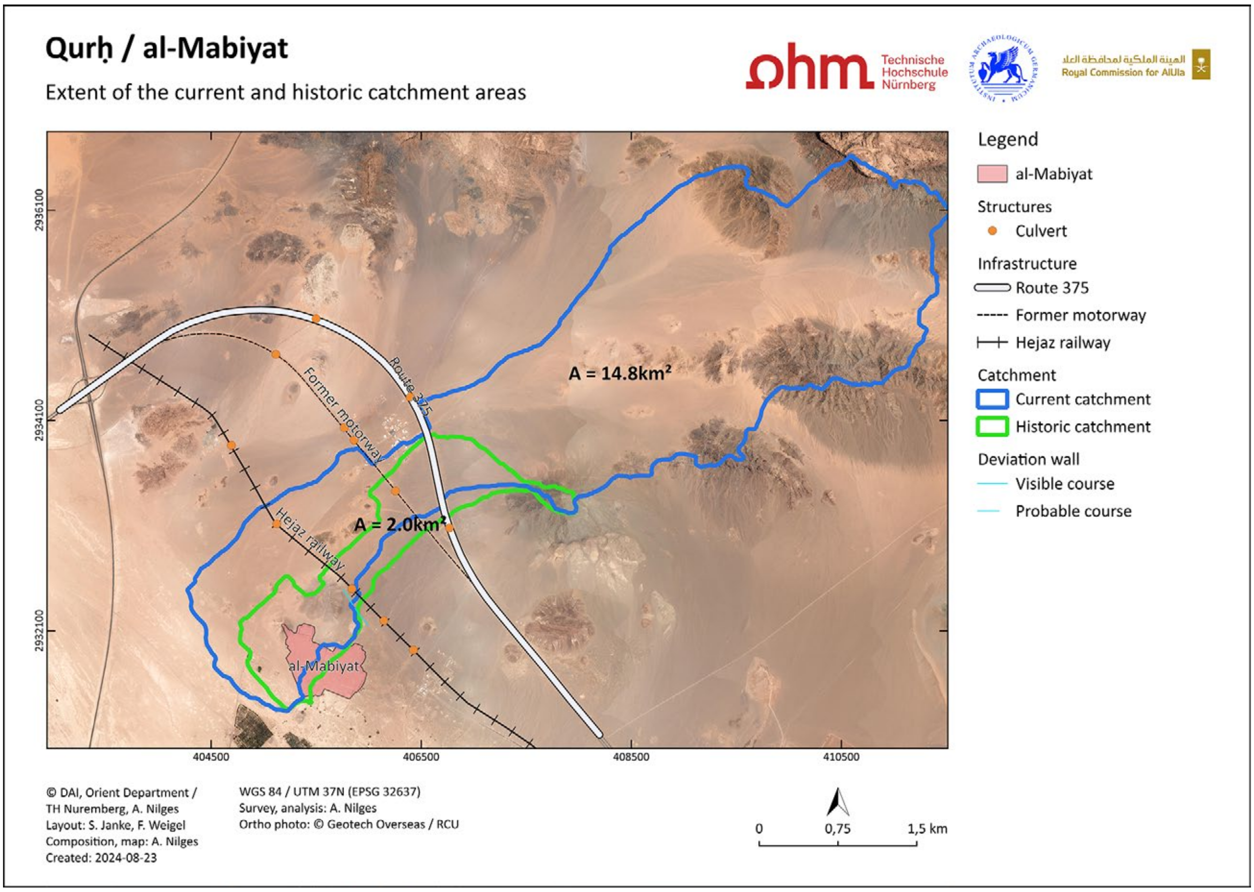

Figure 5. Modern and historical catchment areas affecting the site of Qurḥ / al-Mabiyāt (© DAI, Orient Department / TH Nuremberg, A. Nilges).

motorway Route 375 which connects the airport with the town of al-ʿUlā (Castelli 2021; Figure 5).

South of Route 375 there is the remaining embankment of the predecessor motorway. At a distance of approximately 870m towards the south, running directly north of the fenced archaeological site, is the embankment of the former Hejaz railway. These embankments, which traverse the terrain and its consistent southward declination, function as dams and were thus equipped with culverts to safeguard the structures from the impact of intense flooding. Surface run-off is redirected by these structures. It is notable that the boundaries of the catchment frequently correspond with the positioning of the culverts, which illustrates their significant impact on the flow paths.

The impact of culverts on surface run-off is evidenced by the presence of erosion basins above the structures and deep erosion channels below the culverts. The latter are partially aligned with the direction of flow towards the fenced area and subsequently into the archaeological site, indicating the need for countermeasures and / or differing conditions in historic times.

Historical catchment and flood protection

In order to determine the historical catchment, the embankments of the roads and of the Hejaz railway were removed from the existing terrain model. The terrain levels in these areas were spatially interpolated (using the inverse distance weighting approach) and the topography was thus put into a state that approximates the historical conditions of the region at the time of Qurḥ's major occupation. The resulting catchment covers only 2.0km², which is just the seventh part of the size of the current catchment (**Figure 5**).

Although the historical volume of surface run-off reaching the settlement was considerably lower than that of the present day, the threat it posed remained a significant issue. On this reduced scale it was possible to manage the risk and to utilise the water in a beneficial manner. A wall constructed of stone boulders was built between the large outlier (Mount 2) in the north and a smaller one situated to the east of it (**Figure 6**). The wall runs in a straight line from the north-west to the south-east. The distance between the boulder wall and the city wall varies considerably from 545m (at the north-western edge of the wall to the northern central part

Figure 6. Deviation wall for flood protection in the north of Qurḥ / al-Mabiyāt (© DAI, Orient Department / TH Nuremberg, A. Nilges).

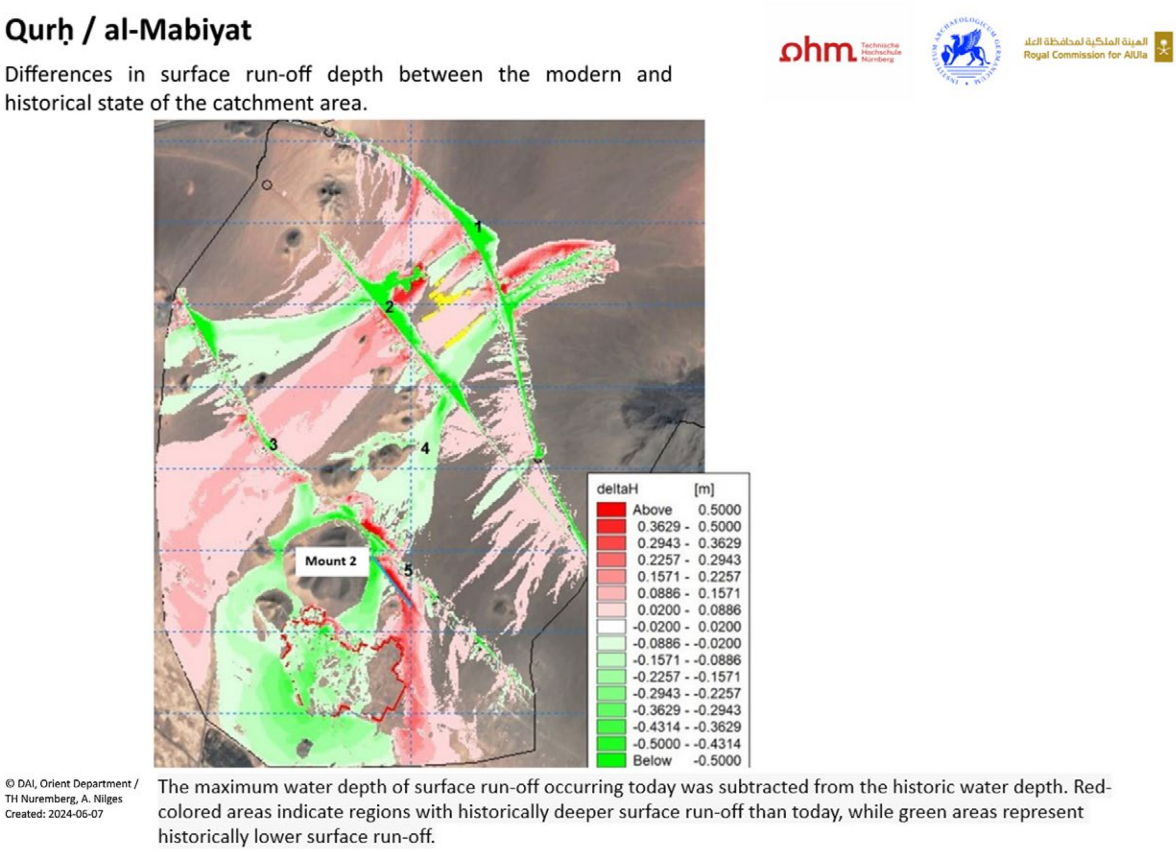

Figure 7. Modelling of a heavy rain event with differences in water levels concerning the modern and historical catchment (© DAI, Orient Department / TH Nuremberg A. Nilges).

of the city wall) to 220m (at the south-eastern edge of the traceable remains of the wall to the north-eastern extension of the settlement). The modern run-off uncovered parts of the wall, showing that the boulders were arranged in multiple courses. In other areas, the wall is covered on both sides with sediments, rendering only its upper part visible. Towards the south-east, though covered by sand, the wall can be traced by a shallow ridge in the terrain, adding to a length of approximately 370m. Its location, as demonstrated by the modelling of the run-off, represents the most efficient for protecting the site from flooding by directing surface run-off around the site. Accordingly, the most probable interpretation is that of a deviation wall (cf. Castelli 2021; Margottini *et al.* 2022: 47).

The remaining water gathering from the erosion channels of the outliers (especially Mount 2) north of the site and below the deviation wall, could have been caught and diverted by the ditch of the city wall, which is mentioned already by Al-Muqadassi and is still well recognisable as a surface feature (for an attempt on excavating the ditch, see Al-Talhi *et al.* 1986: 60) and in the results of a magnetic prospection carried out by QCAP in Spring 2023.

In order to ascertain the extent of surface run-off within the archaeological site, a hydrological-hydrodynamic model (MikeSHE) was employed to generate an unsteady simulation of the catchment area, both historically and in its current state. A 100-year precipitation event was selected as the basis for the design precipitation of 93.52mm occurring over a two-hour period (Nilges 2024). The temporal distribution of the precipitation event exhibits an initial peak form (Euler II distribution), which is characteristic of intense convective rainfall. The models of the historical and present states differ only in their topography. In order to simulate the historical condition, the aforementioned potential flood barrier was depicted as a linear elevation of the terrain by one metre. The difference map illustrates the discrepancies in the water depths of the surface run-off resulting from the heavy rainfall. Areas coloured red indicate regions with historically greater water depths in comparison to the current state, whereas green areas demonstrate shallower water depths (**Figure 7**).

The reduction in water levels observed in the areas situated above the embankments (see **Figure 7**, points 1 to 3) illustrates the damming effect that they exert. The increased surface run-off above and below point

3 also demonstrates that during the period of urban settlement, the flow paths of surface run-off from the side valley ran primarily in a north-westerly direction, rather than directly towards the city as is the case today (area 4). The historical evidence indicates that the surface run-off conditions were not a significant threat to the city and its inhabitants. This is evidenced by the observation that the water depths in the area surrounding Mount 2 and within the city walls are up to 0.5m shallower than the current levels. A comparison of the two models also permits an evaluation of the probable suitability of the deviation wall as a flood protection structure. The model of the historical condition demonstrates the water-conducting effect of the intact wall, which to a large extent permitted the surface run-off from the overlying catchment area to flow past the east of the city (wall).

Birkah's outside the walled settlement

A notable concentration of low mounds ("Ruins A" in Parr *et al.* 1970: 199) and a rectangular depression of c. 48m by 48m are situated to the south-east of the walled settlement. The boundaries of the depression are marked by considerable accumulations of freshwater snails. These unexcavated ruins have been comprehensibly interpreted as a *birkah* (a large tank, reservoir or cistern for storing water; Gilmore *et al.* 1985: 112; henceforth: "*birkah* 1"). Without direct evidence, it remains unclear how the *birkah* was fed and drained. The exploitation of surface run-off might have been an option, as deviation walls such as that in the north of the site might have been used for collecting and channelling incoming water. However, material evidence for this hypothesis is lacking and can only be tested by future excavations. Another probable possibility is suggested by the report of Gilmore *et al.* (1985: 112) of remains of an underground canal in a depth of 2.5m which was cut by a bulldozer trench on a farm 50m east of *birkah* 1. It has been reported that a *qanat* system extended towards al-Mabiyāt enabling to have sustained an agricultural belt along the main valley landscape of al-ʿUlā towards Mughayrah in the south (Nasif 1988: 165–166). Remains of this system in the surrounding of al-Mabiyāt have been surveyed and mapped recently by the al-Ula Cultural Oasis Project (Rosak *et al.* 2025).

The low mounds in the south of *birkah* 1 have been observed to contain a variety of materials, including fragments of bricks and plaster, as well as pottery (cf. Parr *et al.* 1970: 199). In light of Al-Muqadassi's accounts, Gilmore *et al.* (1985: 112) postulated that these mounds adjacent to the *birkah* may signify the vestiges of an extramural bath.[8] However, such interpretation cannot be verified without excavations.

To the south-west of the site, another low depression of c. 25m by 28m with an adjacent smaller structure of c. 11m by 14m may represent the remains of a second *birkah* (2).[9] As with *birkah* 1, the source of the water remains unclear as no surface remains can be directly connected to run-off harvesting or underground *qanat*s without further archaeological evidence.

The water of the *birkah*s as open water reservoirs was not suitable for drinking but could have been used for irrigation, livestock, or production. The latter could be indicated by a kiln area (Al-Aboudi 2019: 37) next to *birkah* 1 (if contemporary) and a substantial ash mound 350m east of *birkah* 2. The settlement is situated on an elevated topographic position in relation to the *birkah*s, which makes it less probable that both structures would have provided water for residential purposes. Additionally, the open construction of the *birkah*s allows for the evaporation of the stored water, rendering them unsuitable for long-term storage. During the summer months, evapotranspiration in al-ʿUlā reaches a mean value of 17mm/d (Huber 2023: 22), which results in a water loss of 0.5m per month. However, a branch of the *qanat* system is directly heading towards the structure from west (Rosak *et al.* 2025: fig. 8 "OS_19680").

Water management in the city

Theoretical implications

Investigating the water supply of the settlement stimulates debate about the minimum amount of fresh water required to sustain the entire population of Qurḥ. The current data set allows only for very rough estimates, as many variables have to be taken into consideration. However, if it is assumed, that one person required about 30 to 40 litres per day to satisfy the most basic needs (e.g. drinking, cooking, washing; McIntosh 2003: 68; cf. Watkins 2006: 2, 35 with 20l minimum), which might be a reasonable figure for arid areas (cf. Gleick 1996: 84–86) and a conservative estimation of the population of Qurḥ between 3500 and 7000 depending on which density (100 to 200 inhabitants per ha) and household sizes are applied (Adams and Nissen 1972: 29; Adams 1981: 69 fn. 6, 144 fn. 1; cf. Zorn 1994 and Madani 2019: 34–41 both with further references), the minimum fresh water supply must have been enough for 105,000 to 280,000 litres per day only for the sustenance of the resident human population.[10]

[8] With the same assumption see Al-Aboudi 2021: 36; cf. Arce 2015 for further examples of such configurations.
[9] This hypothesis has been put forward by U. Siegel.
[10] As a purely dimensional comparison, the overall daily water influx of imperial Rome has been estimated at *c.* 560 litres per capita (cf.

Furthermore, considerable amounts of water for non-resident persons (e.g. traders, pilgrims), livestock, irrigation, construction, supply of public baths and mosques and production purposes would add up to much higher figures for Qurḥ and its agricultural area. Therefore, though probably not of the best quality according to historical sources, there must have been an abundant water supply during the 9th to 11th centuries. Apparently, excluding a very considerable decline in the availability and provisioning of water in the 12th century, the mere quantity of water does not seem to be the reason for the eventual complete abandonment of the city. In fact, Yaqut writing in the early 13th century, mentions that Wādī al-Qurā was in a ruinous state and that no one used its waters (Wüstenfeld 1869: 81).

As vessels, tools and many other movable artefacts can be removed at abandoning a house, fixed installations are more likely to stay and be preserved *in situ*. Hydrological installations and their distribution can therefore improve the identification of household units and its social organisation apart from the architectural remains alone. Different houses within a confined space may belong to one household (community), as such can be defined by sharing resources, labour, means of production, consumption and co-residency (Bender 1967; Yanagisako 1979; Netting and Wilk 1984; Netting *et al.* 1984; Hendon 1996). However, these can be configurations of extended families, cooperating and collaborating to satisfy the socio-economic needs of its members. Therefore, only one water supply in such a compound could be used as a common facility by a household community, so that the members of houses without their own water supply but belonging to the same compound did not rely necessarily on public water facilities. This strengthens the tendency of segregation from the public sphere and the self-management of household communities (Brown and van Berkel 2024: 92–97; Insoll 1999: 78–85). However, that does not exclude that this could express an internal dependency on the provider(s), who might have been the leading members of extended households.

Organisation of urban space and its surroundings is in constant interaction with the environment, its constraints and potentials for human intervention (Ingold 2000: 172–189; Rasolondrainy 2021: 10–23). The particular circumstances and solutions for the provisioning of water have an influence on both the spatial layout, location of main arteries of transportation and the social configuration of settlements and their development (Montalbano 2008: 680; Williams 2018: 163–165, 174–176; Brown and van Berkel 2024: 81–86). However, it is a common pattern that elite households cluster around the water supply of highest quality and less wealthy households further down the lines of supply (Montalbano 2008: 716–720). It is noticeable, that the main streets of Qurḥ form rather linear arteries and follow the general topographical gradient from north-west to south-east, which could also coincide with a potential linear water supply (e.g. *qanats*). The access to water and its provision facilities are therefore important aspects for the social analysis of household units, which can go beyond the pure interpretation of dead ground plans towards the reconstruction of living household systems embedded in an urban fabric. Whether all households or household communities in Qurḥ had their independent access to water, or such amenity was restricted to elite households with others depending on public supply, is a crucial and still open question.

Water supply

The availability of fresh water as a vital resource, coupled with the disposal of grey and black water, has been a pivotal factor in shaping urban living, both in residential and public contexts (Montalbano 2008). Although the urban fabric of Qurḥ, judged by LiDAR and magnetic prospection data, does not adhere to an absolutely regular grid pattern, it is evident that the city's main streets, which run in a north-west to south-east and north-east to south-west orientation, align in an apparently planned manner (cf. Kennedy 1985: 16–17; Brown and van Berkel 2024: 82–86). In this pattern, each household is situated in relative proximity to at least one of the main streets. It appears that minor streets and alleys may have confined smaller neighbourhoods (Akbar 1989; Ismail 1972: 116–117), potentially comprising households or household communities. This material pattern may indicate the existence of a socio-economic organisation, in addition to public institutions, which could have constituted a segmented society centred around households and their relationships (Pini 2019: 11–16; see also Whitcomb 1996: 46; Northedge 2017).[11]

During the excavations of KSU in the north of the city between 2004 and 2019, several residential buildings, streets and alleyways were exposed (approx. 0.4ha) which provide an example of the general organisational pattern of the urban space (cf. **Figure 4**; KSU1). The following observations are based on a detailed recording of the exposed excavation trenches in the context of QCAP.

In seven houses, several installations for the provision of fresh water such as "wells" or cisterns[12] and the

Deming 2019: 156–157 and Hansen 1983: 267 with extremes between 189 and 1135 litres).

[11] For critical discussions of earlier assumptions on "Islamic cities" see Abu-Lughod 1987; Raymond 1994; Alsayyad 1996.

[12] As none of the shafts have been excavated to the bottom, it remains unclear whether they may have been connected to underground hydraulic structures (e.g. *qanat*s, respectively *aflaj* as assumed

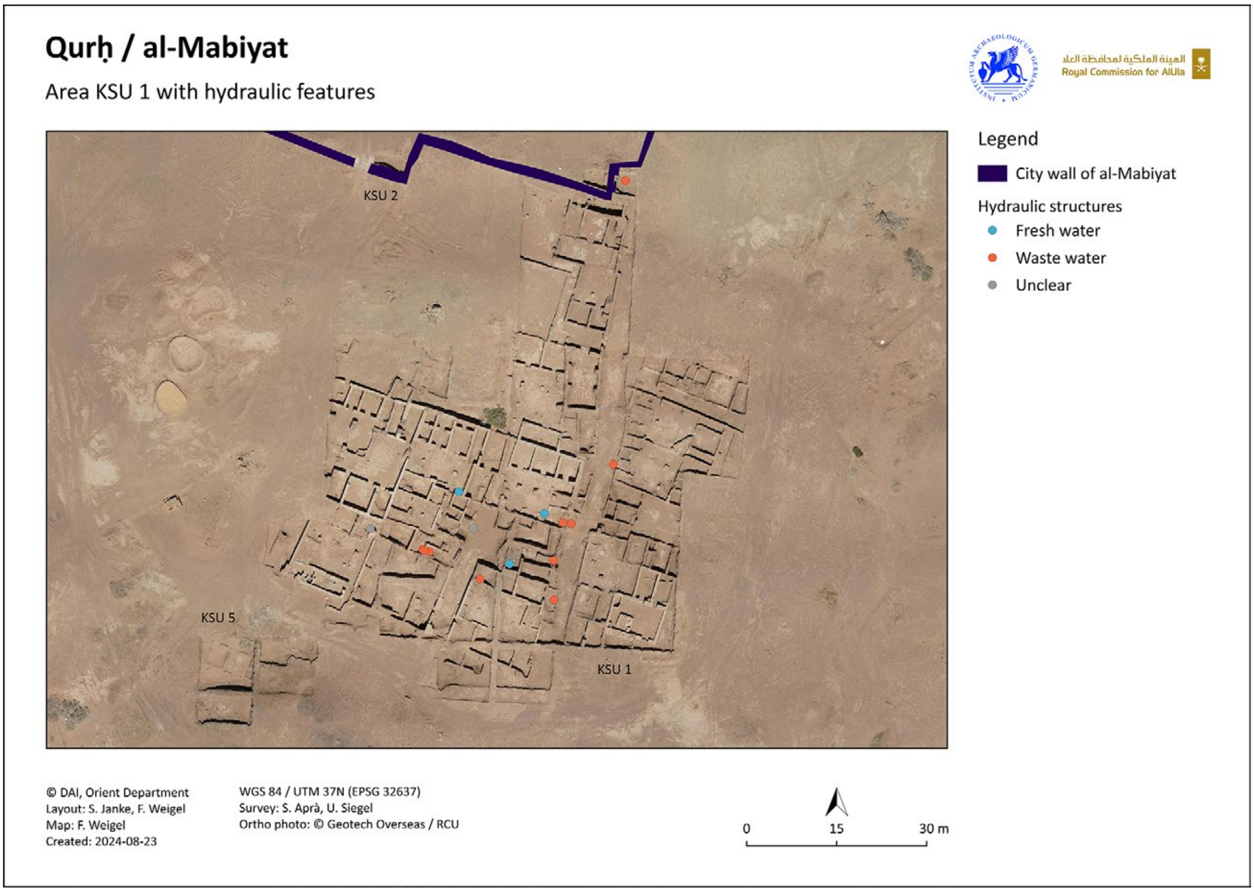

Figure 8. Distribution of hydraulic structures for fresh and waste water in a residential area excavated by the KSU (© DAI, Orient Department, F. Weigel).

discharge of waste water like latrines with canals leading through the walls into cesspits have been preserved (**Figure 8**). Given that adobe is not an appropriate material for prolonged contact with water, the majority of the installations have been constructed using sandstone and fired bricks. Such structures have frequently been coated with a distinctive grey plaster, comprising ashes and burnt materials, which exhibits properties analogous to *pozzolan*. Subsequently, a supplementary layer of hard white lime plaster was applied. The application of this two-layered plaster appears to have been selected systematically for hydraulic structures, with its composition deliberately chosen according to hydraulic properties (Al-Zahrani 2009: 99; Saleh 2013: 69–74, 77).

Access to freshwater shafts was provided via openings in the floors of the houses themselves. It can be observed that the majority of these structures are cylindrical in shape, with their walls strengthened by stones to a discernible extent. The openings are typically smaller than the diameter of the shafts, with either a rectangular (with edge lengths varying between 0.15m and 0.45m) or circular opening (with c. 0.35m diameter in average). The shafts can lead more than 2.60m into the ground, but their lower ends have not been reached.[13] Additionally, there is a probable installation for the provision of fresh water originating from the interior of a house and extending towards the street, potentially for public access (which could also be a symbol for charity). Aside from this exceptional case, the fresh water supply was situated within the boundaries of houses, which constrained access but enhanced the household's autonomy from communal provisioning (if available).

Waste water management

The presence of several hydraulic elements provides evidence that the settlement of Qurḥ also had a

elsewhere, Al-Aboudi 2019: 139–140). Such systems would surely have had an impact in urban layout, spatial distribution of public and private sectors as well as the urban social configuration (Montalbano 2008: 716–720) and organisation of engineering, managing and maintenance labor. For other intra-site subterranean water systems, though under different geological conditions cf. Scanlon 1970: 188–194.

[13] Based on measurements from hydraulic structures of the KSU areas taken in the field by U. Siegel and S. Aprà.

sophisticated system for the disposal of wastewater. Three of these features are latrines, which serve to exemplify a high standard of sanitation. Two hydraulic structures appear to be well-constructed cesspits. The latrines and cesspits were connected by covered canals. The cesspits are positioned in a systematic manner on the external walls of the buildings situated along the street. Consequently, it was feasible to regulate and clean the pits without entering the domicile (**Figure 8**). It remains unclear whether the constructors, maintainers or cleaners were organised in a collective manner, potentially under the direction of a *muḥtasib* (cf. Scanlon 1970: 183), or whether they were household members (cf. Brown and van Berkel 2024: 92–97). The waste water shafts can be circular or rectangular with diameters between 0.38m to 0.54m. They can have a depth of more than 3m, bottom not reached. The separation of waste and fresh water shafts by a distance of at least 2m ensures the maintenance of a secure water supply, with the filtering effects of the soil employed (applying different standards than today).

A further example of a hydraulic structure was found in Area B of the DAI-RCU excavations (see **Figure 4**). This evidence demonstrates that sophisticated hydraulic installations were not confined to the residential area excavated by the KSU but were widespread throughout the city. It consists of a sandstone pilaster with a shaft in which a vertical ceramic pipe was set (**Figure 9**). The shaft was sealed with plaster, concealing the pipe but also facilitating quick maintenance. The hard, grey mortar of the pilaster further confirms its application for hydraulic structures (see above). The preserved height of the pilaster from the bottom to the top is 3.25m and the diameter of the pipe is 0.16m. The water came apparently from an upper storey or roof, probably for draining rain or excess water to be discharged into the ground c. 1.60m below the floor level (there are no indications of a cesspit).

A similar structure, this time combined with an indoor latrine and walled cesspit on the street was also found in the KSU excavations (Al-Omeer 2006: 122–123, pl. 10.3a–b; Al-Aboudi 2019: 143, fig. 90), again demonstrating that such general techniques might have been commonly applied for residential buildings during the 9th to 11th centuries (cf. Leisten 2003: 143, fig. 82, 90; Milwright 2010: 93 for similar examples).

Discussion and Conclusions

Water sources appear to have been much more abundant during the most extensive period of Qurḥ's occupation in the 9th–11th centuries than they are

Figure 9. Ceramic pipe inserted into a sandstone pilaster for drainage purposes (© DAI, Orient Department, F. Weigel).

today. Surface run-off posed less risk during this period because the catchment was much smaller before the impact of modern infrastructure projects. The remaining surface run-off was diverted by a wall around the site and possibly by the ditch along the city wall. Probably associated with these flood control measures and/or supplied by additional sources (e.g. *qanat*s), two extramural *birkah*s may have provided water for irrigation, livestock and/or production.

Within the urban settlement, some houses were equipped with fresh water supply systems, while grey and black water was discharged into the ground through cesspits facing the streets. Bearing in mind the difference between architectural and social units, the distribution patterns of such hydraulic installations may indicate social relations within a household or household community that extends beyond the walls of individual houses. Thus, there is evidence of household water management on the one hand, and of public organisation, or communal efforts, on the other, such as flood control and management of surface run-off through the construction of the diversion wall or ditch along the city wall. The *birkah*s are another example of communal organisation, as well as the management and maintenance of all these structures in order to keep them functional. According to historical descriptions of Qurḥ (Al-Muqadassi), other public facilities such as a public bath outside the city and mosques are examples of public water supply on a large scale.

The site of al-Mabiyāt, with its rich set of hydrological structures, provides an opportunity to study a complex water management system at household, site and site-and-environs scales. Different types of installations and their distribution patterns allow the study of social aspects of access, quality and use. Furthermore, these material remains provide key examples for sustainable approaches to water management with sophisticated installations, structures and the systematic use of building materials and pre-modern technologies.

The architectural remains of the *birkah*s and potential flood protection wall demonstrate that the inhabitants of Qurḥ were confronted with significant challenges in terms of their water supply. In arid climates, precipitation represents a significant but inherently unreliable and scarce water source. The precipitation that occurs during heavy rain events exceeds the infiltration capacity of the soil, resulting in surface run-off. This run-off is not suitable for use in farming or other production activities without the implementation of appropriate infrastructure, and it is lost from the perspective of urban water management. Furthermore, the exacerbating flash floods present an additional hazard to the local population and infrastructure. In order to address the dual issue of water scarcity and the potentially dangerous overabundance of water, a series of storage and protection measures were implemented. The *birkah*s enabled the storage of rainwater during periods of abundance, facilitating its utilisation during dry periods. The diversion wall situated to the north of the city and the ditch along the city wall would have effectively diverted the surface run-off from the valley surrounding the urban area. This historic flood protection was designed to accommodate flash floods resulting from the historic catchment area.

During the construction of the motorway, the catchment was significantly increased, yet no measurements were taken to adapt the flood protection to the changed conditions. The consequences of this illustrate that even seemingly minor alterations to the catchment area can have a significant effect on the surface run-off routing and the risk of flash flooding for lower-lying areas. It is therefore recommended that any construction work should be accompanied by a hydrological assessment.

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Chapter 5.
Traditional Irrigation Systems in al-Aflaj Governorate, Saudi Arabia

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Introduction

Al Aflaj is a governorate located within the Riyadh region, with its capital being the city of Layla (**Figure 1**). The city derives its name from oral and historical traditions, as it is famously known as the birthplace of Qays bin al-Mulawwah and Layla Al-'Ameeriya, whose timeless love story has been immortalized in poetry passed down through generations. Layla's village, Al-Ghail, is situated in the vicinity of Jabal Al-Toubad, one of Al Aflaj's most iconic natural landmarks.

Located approximately 300km southeast of Riyadh, Al Aflaj encompasses a number of agricultural villages that lie along the foothills and edges of Jabal Tuwaiq, stretching from its eastern foothills to its western boundaries. Notable villages in the area include Al-Saih, Al-Badee, Al-Ghail, and Al-Hadar, all of which are names that reflect the region's deep ties to agriculture and water systems. The agricultural sector, particularly date palm cultivation, has long been a cornerstone of the local economy. The remains of these agricultural practices continue to be visible today, thanks to

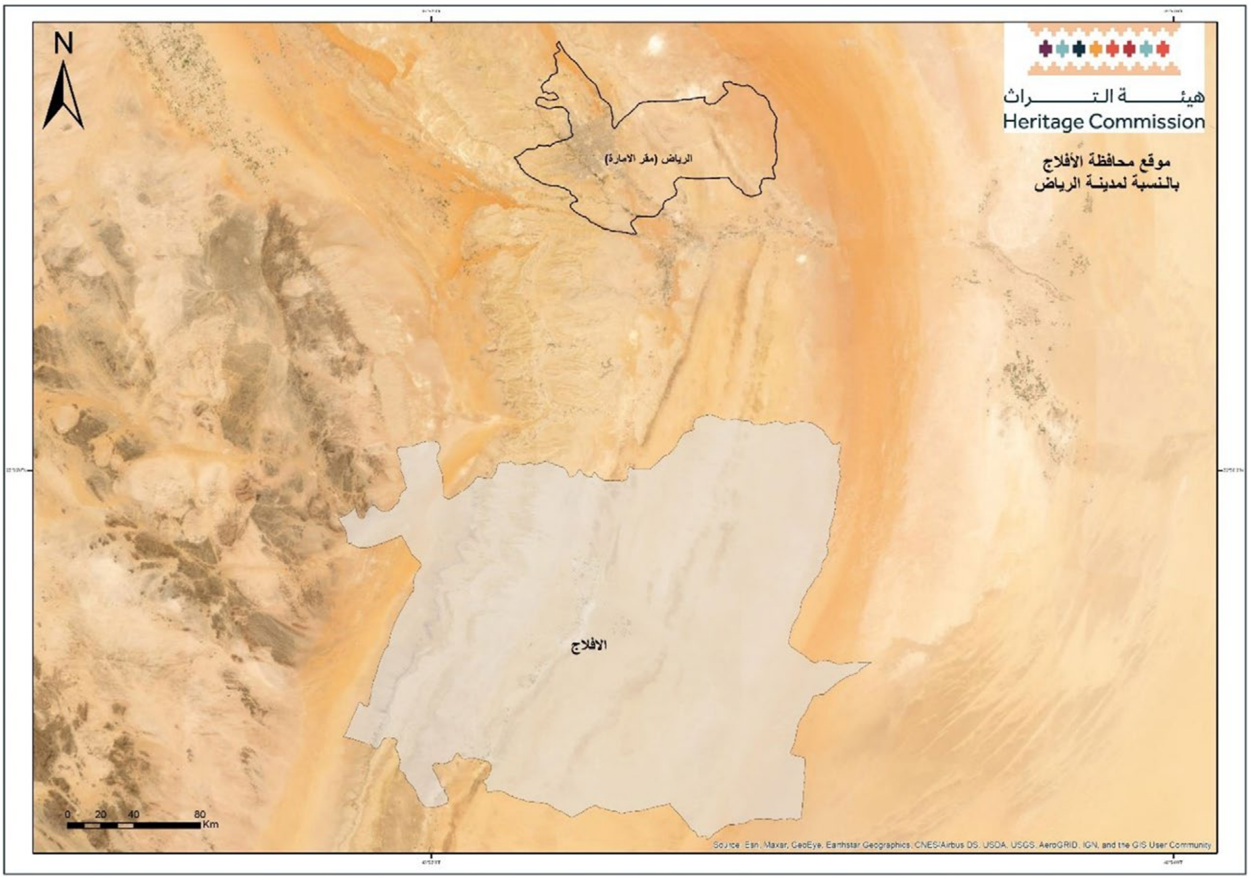

Figure 1. Map Showing the location of Al-Aflaj Governorate.

The Archaeology of Irrigation Technology and Water Management (Archaeopress 2025): 53–60

the region's abundant water resources, supplied by underground channels. Historically, these farms functioned in the traditional manner until 1976, a common occurrence for settlements across central Arabia, particularly those situated in sedimentary formations. The availability of water from springs and wells played a crucial role in sustaining the region's agricultural activities.

Origin of the Name

The region was historically named 'Al Falaj' in early sources, with its plural form 'Al Aflaj', derived from the Arabic root signifying the flow or emergence of water. In linguistic references, '*Falaj*' denotes water flowing from a spring, a fitting description for the region, where its ancient water channels continue to leave their mark to this day.

Al Aflaj in Historical Sources:

Al Aflaj, (also Falaj), was mentioned by the 9th-century historian al-Hamdhani (d. 244AH) as a well-known city in the Yamama region. Yamama, which nearly corresponds to the present administrative borders of the Riyadh region, witnessed significant growth and civilization during the first three centuries of the Islamic era. Historical sources indicate the presence of around forty villages along the Wadi Hanifa, and the region was connected to a network of trade routes linking it to Oman, Iraq, Bahrain, Yemen, and Makkah. Al-Hamdhani also referred to the famous Souq Al Falaj (the market of Al Aflaj), which had over 400 shops and 260 wells, making it a central hub for internal trade within central Arabia and external trade with its southern neighbours. Al-Hamdhani noted the existence of 20 springs in the region.

In the 5th century AH (12th century CE), the Persian traveller Nasir Khusraw, who visited the region in 442AH, described the social conditions and lifestyle in Al Aflaj, noting that they were less developed compared to the descriptions in Al-Hamdhani's account. He mentioned that the region had only four springs, suggesting a decline in agricultural activity due to the loss of over 16 springs and water channels.

In 1918, the famous traveller and explorer Philby wrote about the geography, inhabitants, water channels, and ancient relics of Al Aflaj in his book *The Heart of Arabia*. He described the region's traditional buildings, which he believed dated back to the later Islamic period due to the style of mudbrick architecture. He noted that only one spring remained at that time.

The rediscovery of these sites began with the 1978 archaeological survey conducted by the Department of Antiquities, which published its results in *Atlal* (the Saudi Arabian Antiquities Yearbook). A more comprehensive survey was conducted in 2006, and although these efforts were not linked to excavation activities, they primarily focused on archaeological surveys and documentation of the sites.

In 2020, the Heritage Commission carried out archaeological studies on several water channels related to agricultural activities, revealing a set of basins that, based on initial excavation results, appear to have been used for planting and cultivating date palms. This design contrasts with traditional date palm farming methods, particularly in terms of the spacing between each basin. Hundreds of other basins are buried beneath the site. In mid-2023, the Heritage Commission conducted a survey to document ancient water sources, systematically recording many of these water systems. Furthermore, since 2023, the Department of Archaeology at King Saud University has been conducting excavations at the site known as Qusayrat 'Ad, with preliminary findings based on the study of artifacts, architecture, and laboratory analysis of organic materials, indicating a historical overlap with the Al-Faw archaeological site.

These ongoing efforts contribute to the growing body of research on Al Aflaj, shedding light on aspects of the region's cultural heritage and addressing unresolved questions regarding the historical sequence of the site and the activities reflected by the discovered archaeological structures. These findings provide valuable insights into the role of the people of Al Aflaj in various aspects of life and their connections with other cultural centres across the Arabian Peninsula.

The Landscape of Al Aflaj

The region is traversed by the famous Jabal Tuwaiq, particularly in its western part, and is rich in valleys and ravines. Along the sides of these valleys lie several villages, including Haradah, Sattarah, Al-Ghayl, Al-Haddar, and Al-Ahmar. Among its most notable valleys are Wadi Bark, Wadi Talha, Wadi Shattab, Wadi Haradah, Wadi Al-Ghayl, Wadi Al-Ahmar, and Wadi Al-Haddar, which have historically been vital sources feeding natural springs. Historical sources refer to these areas as Siyouh (water flowing over the ground), such as Siyh Ishaq, Siyh Al-Zahmadi, and Siyh Al-Riqadi, along with other notable springs, the most famous of which is Ain Al-Raas.

Irrigation System through Water Channels

This system is designed to pull water over long distances through a long underground tunnel. It originates from the main well, known as the Main Well (**Figure 2**), which is typically located in a relatively high area. The tunnel is punctuated by vertical wells, spaced several meters apart (usually 4 to 5m), and the depth of these

Figure 2. Drone image showing one of the main dry springs, which was the primary source for feeding the channels (main well).

wells decreases as you move further from the main source (Main Well). In the final point of the system, the water flows out to irrigate fields and agricultural areas.

This system has been known in various regions around the world, including in Al-Asyah in the Qassim region, Al-Ula in the northwest of the Kingdom, Yanbu on the Red Sea coast, as well as in Bahrain, Oman, the UAE, Persia, and other countries and regions.

How the Channels Work

This system and technique reflects ancient human knowledge, experience, and understanding of the land's topography. It involves a series of steps that can be summarized as follows:

1. The conduit is dug in a high location, which may even be a natural spring that humans have maintained by cleaning and deepening it whenever the water level drops. Water is then transferred underground over varying distances, through a long tunnel punctuated by vertical wells every few meters (**Figures 3 and 4**).
2. The work begins underground, filled with various difficulties and dangers. The worker digs in a dark area, using a light source. When the light goes out, they must dig a hole in the ceiling to allow oxygen to flow. This process continues until they reach the last vertical well, known as the *kharaz* (also means 'beads' in Arabic).
3. The depth of the openings gradually decreases until they reach the main area, where the water flows out onto the ground.
4. A framework is built around these wells, raising them slightly above the ground, with what resembles a neck to make them visible and prevent people or animals from falling into them. These wells help regulate the flow of water, and they are also used for manually drawing water when needed. They were also used to remove debris from the tunnel when constructing the channels. Workers use them for maintenance and cleaning whenever necessary to repair any blockages or obstructions in the tunnel caused by natural elements or vandalism.

Advantages of Water Channels

This water system offers several advantages, including preventing water evaporation. It also reduces the significant effort and energy required to transport water over long distances. The system utilizes surface wells (*kharaz*) for cleaning and maintenance, controls the flow and distribution of water as previously mentioned, and the *kharaz* system is commonly used in central Arabia for these water systems. This may have been named due to the similarity in the sequence

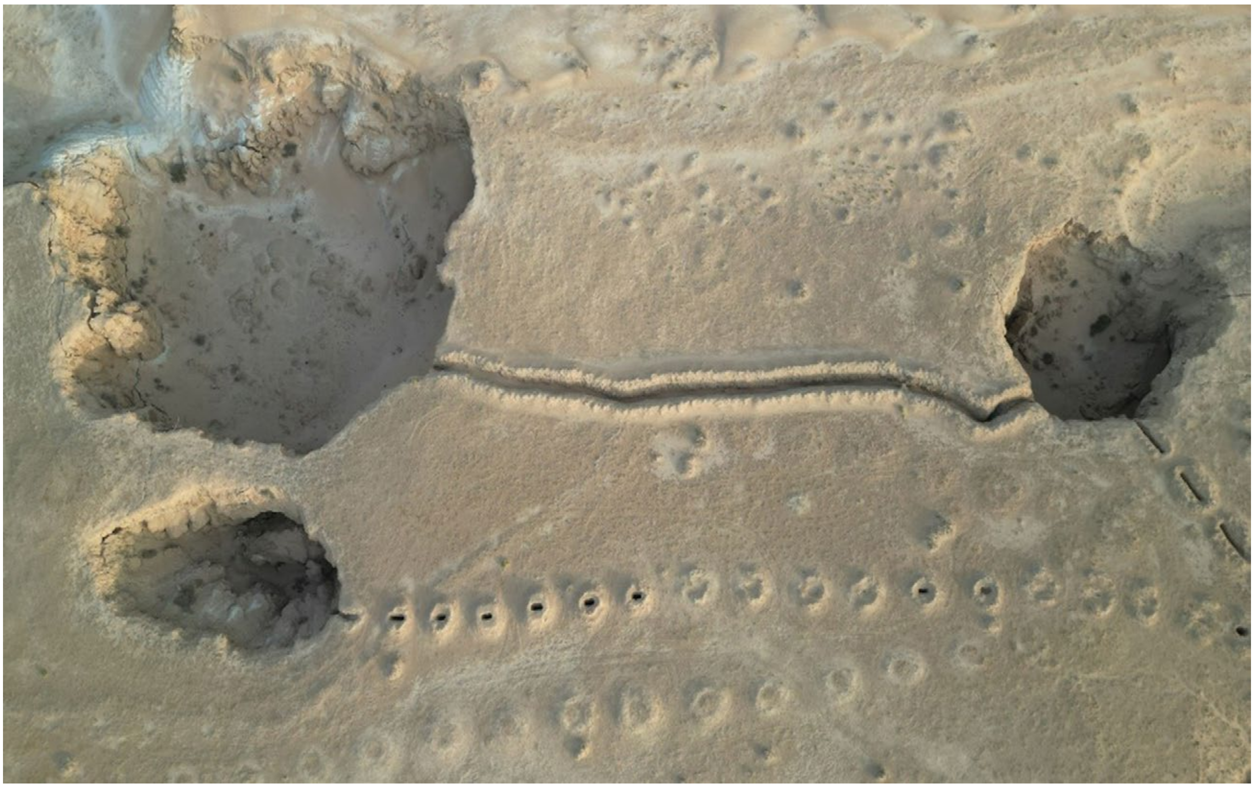

Figure 3. Drone image showing the main springs and the extension of channels from them, displaying traces of extinct channels alongside more recent ones.

Figure 4. Drone image showing the extension of channels, highlighting traces of extinct channels alongside more recent ones, illustrating the density of water channels in Al-Aflaj Governorate.

of wells along the channel, resembling the beads on a piece of clothing.

History of Al Aflaj Water Channels

This water system is one of the most widespread irrigation methods in the world. Historical sources discussing economic and agricultural reforms in the Arabian Peninsula provide various details, including that Caliph Uthman ibn Affan sent workers to the Nafi region, near the present-day Qassim, to dig wells, with many shafts dedicated to this purpose. Agricultural investment continued during the reign of Muawiya ibn Abi Sufyan, who brought over 4,000 slaves with their families to work on his farms in Al-Yamama.

The irrigation in Al Aflaj wells, which numbered over 20, flourished, as described by Al-Hamdani. This system continued to thrive for the first three centuries of Islam but began to decline in the 5th century AH. A historical source mentioned by the Persian traveler Nasir Khusraw in his book *Safarnama* states that during his visit, only four channels remained in use for irrigation, indicating that many channels had disappeared by that time. In summary, the Al Falaj system developed and thrived throughout the Umayyad and early Abbasid periods. However, it eventually ceased due to the high cost of repairs, skilled labour, or the hazardous nature of the work.

Archaeological evidence provides more detailed information about this water system, which was known before Christ in various parts of the world. It resembles the water systems in Persia, which were known in the 8th century BCE. The irrigation channels in Al Kharj (one of the well-known settlements near Al Aflaj city) have been dated to the Hellenistic period due to the discovery of pottery from that time. Similarly, in the Arabian Gulf countries, such as Oman and Al Ain city in the UAE, some studies suggest that these systems date back to the Sasanian era. In Bahrain, ongoing fieldwork is expected to reveal more about the origins of these water systems. Understanding the priority of one location over another, it becomes clear that human experiences will continue to evolve, with the implementation of such systems being influenced by local interests, societal needs, and economic benefits.

As for the water channels in the study area, they have recently been subjected to archaeological studies, some of which have written the history of these channels (**Figures 5 and 6**). The analysis of organic samples from charcoal primarily traces back to the 1st century BCE. The archaeological evidence regarding Al Falaj channels is based on samples that have been validated due to their consistency, especially those taken from the Hudaj channel, which is connected to the most important archaeological site in the area. The reference history for these samples spans from the mid-3rd century CE to the 9th century CE. Additionally, the probes at the Sidah site (site number 251) revealed reference histories extending from the 8th to the 11th century CE.

Figure 5. Aerial image showing the extension of the water channel, featuring the closely spaced openings known as *Kharaz*.

Figure 6. Distribution of the water conduit network in Al-Aflaj.

Causes of Decline and Cessation of Operations

It is clear that security and economic stability were the primary factors ensuring the continuation of economic activities, including agriculture and irrigation. The channels could only survive under strong and secure conditions, as they were vulnerable to damage and required substantial funds for maintenance and upkeep (**Figure 7**). Moreover, the presence of skilled labour was essential, but it likely declined or became unavailable. This is evident in the field studies, which reveal that some open channels were used for water transportation, but the water would evaporate in this manner. It appears that these channels were still used by residents after the departure of skilled workers. Other, older channels are now barely discernible, existing only as underground sunken depressions.

In later periods, excessive water extraction became one of the main causes of the depletion of the primary wells that supplied these channels, all of which drew from a single underground reservoir (**Figure 8**). Local residents indicate that these channels continued to operate, albeit in limited forms, until the last century.

Conclusions

These water channels originated in the region during the first millennium BCE, in response to the needs of the population, who did not remain passive in the face of natural challenges. They harnessed their resources and knowledge through multiple experiences. The channels flourished during the early Islamic period in the 8th and 9th centuries CE. However, as this technique could only thrive under conditions of security and a strong economy, it was vulnerable to destruction due to weak security. Additionally, the high costs required for maintenance and care, coupled with the lack of skilled labor, contributed to its decline.

The channel system in Al Aflaj region closely resembles those found in Iran, Oman, Bahrain, Algeria, China, and Morocco. However, it differs in its water source. In specific regions, the water is sourced from beneath the mountains, as seen in Iran, China, and others. In contrast, in Al Aflaj, the water comes either from lakes, depressions, valleys, or underground layers.

The names of this water system vary from place to place, despite the similarities in its execution and function. In the Al Aflaj region, it is referred to as the '*kharaz*' system, while in Oman and the UAE, it is called the '*Al Falaj*' system. In Bahrain, it is known as the '*Fuqba*' or '*Thaqb*' system, referring to the adjacent wells. In the Maghreb countries, it is called the '*Fuqara*' system, in southern Arabia the '*Ghyoul*' system, and in Persia, it is known as the '*Kahriz*' system.

Figure 7. Drone image of an extinct water conduit no longer in use to the left, and a more recent one on the right.

Figure 8. The inside of one of the Al-Aflaj water channels.

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Chapter 6.
Old Water Structures in the Islamic City of al-Rabadha on the Hajj Road from Kufa to Makkah

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Introduction

In the name of Allah, the most gracious, the most merciful

Allah Almighty says in His Wise Book: 'And you see the earth barren, but when We send down upon it rain, it quivers and swells and grows [something] of every beautiful kind' (Al-Hajj: Verse 5). Allah Almighty says: 'Do you not see that Allah sends down rain from the sky and makes it flow as springs [and rivers] in the earth; then He produces thereby crops of varying colours; then they dry and you see them turned yellow; then He makes them [scattered] debris. Indeed in that is a reminder for those of understanding' (Az-Zumar: Verse 21). Allah Almighty says: 'who made for you the earth a bed [spread out] and the sky a ceiling and sent down from the sky, rain and brought forth thereby fruits as provision for you. So do not attribute to Allah equals while you know [that there is nothing similar to Him' (Al-Baqarah: Verse 22).

Water is mentioned in more than 45 Surahs, and Earth in more than 72 Surahs. The words 'your land', 'our land', 'their land', and 'my land' were also mentioned in the Holy Quran. The water, earth and sky contain the divine miracle of life and its continuity. Water is the lifeblood of humans, animals, and plants, and it led to successive human civilizations (Al-Abadsa 2002; Obaidiya 2003; Bin Abdullah 1996: 121). The Arabs throughout history are one of the peoples who have developed cultures and civilizations based on rain, flowing torrents in the valleys, or underground springs or streams, and from which humans, animals and plants benefit and prosper in the land.

Arab heritage books and dictionaries have provided us with a rich culture about the concerns of the Arabs on their so-called barren peninsula, and their connection to water resources and pasture habitats. Literary and linguistic resources talked in more detail about Arabs' care for valleys, their names, and their water courses more than any other landforms (Hamad 2007; Azab 2023).

The Arabs defined valleys and described their shapes, from upstream to downstream. They distinguished in their names between new valleys and old ones. According to their linguistic definition, the valley is the lowland in which torrents flow when it rains, between the mountains and hills. The Arabs defined the valley's water dividing line with one word, 'al-Sila', which is the cleft in the mountain. There were many names for the divisions of the valleys and their courses, from mountain peaks, rain fall, and torrents to the lowest point the valleys reach. The Arabs also defined the names, features, and topography of the valleys, their rocks, sediments, slopes, twists, sides, bottoms, and types of soil.

The Arabs had various names for the valleys, some of which are still known by their ancient names in the Arabian Peninsula. Some valleys are named after the places where they flow or the names of the tribes living around the valleys. Some of the most famous of these valleys are Wadi Al-Aqiq, Wadi Al-Ays, Wadi Bisha, Wadi Tathleeth, Wadi Al-Dawasir, Wadi Hanifa, Wadi Al-Rumah, Wadi Al-Sarhan, Wadi Al-Maiah, and others. In Arabic, there are some terms that describe valleys, their breadth, slope, and the terrain in which they flow, including Al-Abtah, Al-Battin, Al-Talaa, Al-Thaghab, Al-Jarboub, Al-Jarjoub, Al-Hajar, Al-Hazim, Al-Hadaba, Al-Khar, Al-Khor, Al-Dahla, Al-Sakia, Al-Saqah, Al-Sar, Al-Salil, Sharia, Al-Shaab, Al-Shuaib, Al-Shaghiyya, Al-Aiba, Al-Fahl, Al-Farsha, Al-Faydah, Al-Quray, Al-Mhanab, Al-Mukhaj, Al-Madhah, Al-Mala'a, Al-Maitha, Al-Hathloul, and others (Al-Suwaiyan 2000: 277-348).[1]

Throughout history, Arabs have been interested in knowing about water resources. Most of the places mentioned in poetry books and geographical, literary and linguistic dictionaries related to the Arabian

[1] On the practical, scientific, engineering, and technical knowledge of the Arabs before Islam, see: Dalu 2007: 305-325.

Figure 1. 1. Ghadir Ruwawah one of the well-known natural water sources near Madinah. 2. Ghadir Ruwawah in the dry season. 3. Pilgrim Roads - early Islamic period. 4. Islamic World in the 8th century AD. 5. Darb Zubaydah, the pilgrim road from Kufah to Makkah. 6. Octagonal cistern at Faydah on the Darb Zubaydah. 7. The well at Zubalah very deep ,with plentiful water, Northern District, Saudi Arabia. 8. An ancient well at Zubalah, round shaft with plentiful water. 9.The remains of the ancient reservoir at Zubalah close to the large ancient well. 10. The remains of of Zubalah reservoir after the end of the rainy season.

Peninsula are in fact names of water resources. These water resources were linked to the tribes settled near them (Bin Abdullah 1996: 84-96). (**Figures 1.1 and 1.2**).

> The history of Arabs in pre-Islamic times is eventful, including fierce wars and battles over water and pasture. The Arabs have knowledge accumulated over the ages before and after Islam about water reservoirs underground. They devoted all their energies to extracting underground water by digging water wells and springs and making canals to provide water for drinking and irrigation. The Arabs also gained unique experiences in monitoring water reservoirs in remote places between mountains and sand dunes (Al-Athari 1984; Samar 2016; Braunlich 1924-1926).

The well, with its various names and techniques, has been directly linked to lives of nomadic and urban people throughout the ages. Names of the wells include Al-Jub, Al-Rakiyah, Al-Qalib, Al-Hassi, Al-Rass, Al-Iad, Al-Hafar, and Al-Jafr. Each of these names has a cultural legacy among Arabs in their lives. Water reservoirs and resources also have several names, including Al-Thamd, Al-Thamila, Al-Mashash, Al-Uqla, Al-Qalta and others (Ibn Manzur n.d.: 199, 503, 507, 532, 640, 923-924, 1641, 1722, 2835, 3050, 3715, 4209; Bin Abdullah 1996: 77-79).

Water resources played a prominent role in locating nomad and urban settlements, based on which the routes of caravans, transportation and travel were determined, and road directions were identified (Ali 1993: Volume 7, 317-364, Volume 8, 419-423).[2] Since the dawn of Islam, trade and pilgrimage routes developed to link the cities of the Islamic states to the Two Holy Mosques. For many centuries, thousands of caravans travelled on these routes from China, Central Asia, India, Persia, the Mediterranean basin, the Levant, Egypt, the Islamic Maghreb, Yemen, and Oman. This development was accompanied by the emergence of Muslim engineers who excelled in extracting underground water and made canals, springs, and wells (Al-Karji 1940; Al-Rifai 1989).

The Arabian Peninsula witnessed sophisticated architecture in the construction of water structures, including digging and constructing wells, ponds, springs, canals, and dams. The caliphs, sultans, rulers, nobles and benevolent undertook constructing and supervising wells seeking the pleasing of God Almighty. Engineers and large numbers of workers were entrusted with construction projects. The Arab Islamic civilization flourished in the Arabian Peninsula because of these great projects. Cities, villages, houses, palaces, fortresses, and markets emerged. The Arab tribes and residents who settled on the sides of the roads coexisted with the caravans of pilgrims and merchants. They exchanged the different products, including agricultural products, fodder, industrial products, agricultural crops, food, clothing, and other products needed by travellers on these roads. Companions, followers, scholars, and students from inside and outside the Arabian Peninsula also travelled on these roads, settled in their dwellings, and prayed and worshiped in their mosques.[3]

The existence of these water structures and their various facilities still indicate to us the proud Arab Islamic civilization, but interest in and benefits from these resources have been disrupted due to disasters, strife, and displacement of residents from both outside and inside the Arabian Peninsula in search of livelihood and safety.

Although nowadays we search for water resources in a different way thanks to technical development, people of the distant past are still superior to us in their respect for the environment and appreciation of water which is the most important resource in human life. In this context, we shed light on one example and one of the unique experiences of the early Muslims in searching for water and its engineering on the most famous route in the Arabian Peninsula in Islamic times (**Figures 1.3 to 1.5**). It is the Kufa/Makkah Hajj route, historically known as the Darb Zubaydah. The value of this route lies not only in its history, civilization, and the remaining water facilities and historical and cultural landmarks along it, but in the scientific, technical and engineering aspect of the path of the road and its branches, its connection to the population and impact on human settlement throughout Islamic ages, and in the areas it traverses with their various topographical and environmental diversities.

The Darb Zubaydah extends from Kufa, Iraq, and heads south and southwest, crossing diverse terrain that combine rough, flat, and high areas interspersed with rainwater streams and valleys, and easy-to-pass desert areas, or rugged ones, with their sand dunes and low valleys. There are flat plains areas and mountainous and rocky areas, difficult to pass and penetrated by narrow valleys. On the path of this route, stations and houses were established at close distances. Each station was provided with wells, ponds and other facilities for travellers, local, and desert residents. The main road is intersected with other paths branching off to neighbouring areas adjacent to the road.

Based on field and scientific experience and extensive studies of this historical road, starting at the beginning of 1393 AH (1973 CE), it was possible to identify many

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[2] On water and dwellings of the Arabs and roads of Hajj, see: Al-Isfahani 1968.

[3] On water and irrigation in Hijaz, see: Al-Ali 1990: 131-15; Maliki 1987.

of the stations, dwellings, facilities, and services on the road. The journey along this road and the subsequent scientific follow-up continues through historical and archaeological surveys, studies, and research (Al-Rashid 1977; 1980).

About 54 stations and dwellings that still exist on the Darb Zubaydah have been identified. There are also many relics and landmarks still remaining on the side roads, most of which are located within the geographical scope of the Kingdom of Saudi Arabia. The road's landmarks begin to appear at Al-Dhafri station near the Iraqi border (Northern Border Province).

Outcomes of the extensive studies of the road's landmarks have:

1. Identified the various engineering systems for construction of water ponds that spread along the road.
2. Identified engineering systems and techniques for drilling wells of multiple depths and sizes.
3. Investigated archaeological sites and architectural landmarks of cities, stations, dwellings, palaces, forts, and houses inhabited in the Islamic ages.
4. Identified industries that were associated with people's lives, including pottery, ceramic, metal, stone, and other materials.
5. Identified the geographical environment of areas through which the road passes, its branches, and the villages and dwellings inhabited in the oases and on the banks of the valleys.
6. Identified water reservoirs far from the path of the road, which were a resource for caravans of pilgrims and merchants.
7. Identified the cultural aspects of nations and peoples that lived along the road or those who travelled along it, including pilgrims, Umrah performers and merchants, through inscriptions and engravings on rock facades.

It must be noted that the Darb Zubaydah, with its many cultural landmarks, witnessed the beginning of its development in the era of the Rightly Guided Caliphs, and during the Umayyad era. The road witnessed its heyday in the first Abbasid era, with the first caliphs, including Abu Abbas al-Saffah, Abu Jaafar al-Mansur, al-Mahdi, al-Hadi, and Harun al-Rashid. The Abbasid caliphs in subsequent eras were interested in repairing, reconstructing and protecting the roads, despite the sabotage and destruction of the road facilities, dwellings and water intakes by the rebellious tribes (Al-Rashid 2018: 94-112). Although the Abbasid Caliphate fell at the hands of the Mongols in 656 AH (1258 CE), Darb Zubaydah remained an indication of the civilization of the Arabs and Muslims, and many of its water facilities remain in use to date.

The number of water facilities identified amounted approximately to 100 ponds and dams. The specifications of the water ponds that were documented and examined are as follows:

- Square Ponds
- Rectangular Ponds
- Round Ponds
- Octangular Ponds
- Terraced Ponds (rectangular, square, and circular)
- Pools with internal terraces.
- Ponds equipped with sedimentation basins (strainers).

Besides the architectural and engineering distinction of Darb Zubaydah ponds, they have a unique architectural and engineering pattern that was revealed in the excavations of the historic city of Fayd, one of the largest historic cities located in the middle of the Hajj road between Kufa and Makkah. These octagonal ponds or fountains are of high degree of accuracy and perfection in terms of construction and water drainage (Al-Hawas 2003; Al-Hawas *et al.* 2010: plates 1,2-2,12). **(Figure 1.6).**

As for wells dug and constructed along the main road of Darb Zubaydah, they, according to information contained in geographical sources, numbered more than 1300. We were able to identify many archaeological wells, some of which are still in good condition and are used to date. Among the most prominent wells that are still full of water and that Bedouins benefit from are the Zabala wells, which are one of the main stations on the Darb Zubaydah. **(Figures 1.7 to 1.10).**

It is clear from our comprehensive study of the landmarks of the Hajj road that the engineers and builders had good experience with the topography of the land in areas the road crosses. This experience enabled them to determine the sites for digging wells, building ponds and dams, and establishing water canal networks with great skill. The engineers and builders worked regularly and maintained the road facilities on an ongoing basis. They worked intensively before the beginning of the movement of pilgrim caravans to Makkah and back. The road had ministers and permanent workers employed by the caliphs (Al-Rashid 2018: 499-201).

Archaeological studies have revealed that water installations discovered along the Darb Zubaydah have a high degree of cohesion. Some of them were preserved by layers of sand and flood sediments, while others are still in use.

Benefitting from Darb Zubaidah

The idea of benefitting from Darb Zubaidah and bringing it back to life began with the foundation of the Kingdom of Saudi Arabia during the reign of King Abdul Aziz. There were initial discussions between the Kingdom of Saudi Arabia and Iraq during its royal era, and an agreement was signed between the two countries on Dhul-Qi'dah 18, 1353 AH, corresponding to February 1935. The agreement consisted of 16 articles stipulating that the two governments would collaborate on facilitating and organizing the passage of pilgrim caravans within the borders of the two countries, seeking to enforce security on the road, determining fees on cars transporting pilgrims, and allocating guides to accompany pilgrims' cars within the borders of each country. The part of the Hajj road to be used started from Najaf and headed along the road located in Saudi territories. The car road then branched off to Hail towards the west, passing through the site of Turabah. From Hail, the car road headed towards the south until Madinah (Al-Rashid 2018: 126; Al-Husseini 1940: 9-11).

Experience of Benefiting from Old Water Facilities

At the beginning of its formation, the Ministry of Agriculture attracted geological experts to conduct extensive survey studies to identify water reservoirs. Reports and research indicated that it is possible to benefit from the ancient water facilities, including springs, wells, ponds, and dams. The Ministry began restoring some of the famous archaeological dams in Khaybar and Taif. Early projects implemented by the state focused on benefitting from the springs of Zubaidah and pumping specific amounts of water through pipes from the springs of Wadi Fatima to Jeddah. There are also agricultural experiments based on natural water resources in the springs of Al-Ahsa and Al-Kharj.

It appears that water ponds along the Darb Zubaidah were part of the Ministry's projects for the benefit of the Bedouins. The Ministry began restoring some of these ponds in selected locations, including the ponds of Al-Dhafiri, Al-Amaya, Al-Jumaimah, Zabala, Al-Hamra, Al-Aqiq, Al-Kharaba, and others. We noted that the Ministry, despite the importance of these works, did not adhere to the technical standards in preserving the architectural, archaeological and heritage identity of the ponds and their surrounding areas.

On Thursday (5/5/1393 AH), corresponding to (7/6/1973 CE), we reviewed the cleaning and restoration work of the (Al-Aqeeq) and (Al-Kharaba) ponds, located west of the Rakba Plain, northwest of Taif. The locations of these ponds were among the most important stations on the Darb Zubaidah. The location of 'Al- Aqeeq Pond' is called 'Al-Ghamra' by geographers. As for the location of Birkat al-Kharaba, it is called Basyan, and the distance between the two locations is about 15km. The water network in Birkat Al- Aqeeq benefits from the torrents of Wadi Al- Aqeeq from the west, and the water reaches Al-Kharaba Pond through an elaborately built ground canal (Al-Rashid 2018: 356-368).

Historical information collected about these two locations revealed that water ponds were hidden under dense dust and mud, with only the upper edges protruding from them. As for the residential buildings that existed in the early Islamic eras, they became ruins. As a result of the cleaning work of the two ponds conducted by the entity implementing the project, wonderful cultural landmarks have emerged, illustrating the engineering creativity of Muslims in the precision of construction and geometric dimensions, as well as the use of building materials of carefully cut stones, strong cementing mortar, insulating plaster layer, thickness of walls, and knowledge of the topography of the earth, watersheds, and taking into account the public interest for the benefit of pilgrim caravans, local residents and passers-by.

Despite the partial destruction of these ponds during the cleaning and reconstruction work, it provided an opportunity to identify the exact measurements of the pond's sizes, depths, and technique of its water supply. Examples include:

Aqeeq Pond

A square pond, terraced on all its internal sides, from top to bottom. Its dimensions at the bottom are 35 x 35m, and at the upper edge are 49 x 49m, and it is 5.5m deep. The upper wall at the beginning of the thresholds is about 1.5m above ground surface and there are 10 thresholds descending to the bottom of the pool. (**Figures 2.11 to 2.14**).

Al-Kharaba Pond

It consists of two adjacent pools, the first of which is rectangular and terraced. Its dimensions in the upper part are 35 x 28m and its area at the bottom is 22 x 12m. It is 5.79 metres deep, and it has 11 descending thresholds from top to bottom. This pond serves as a filter that receives water through a ground channel from torrents and rain that feed Wadi Al-Aqeeq. The other main pond is very large and completely terraced. Its diameter at the upper edge is about 54m and at the bottom about 40m. It has 11 thresholds from top to bottom and is 4.84m deep. There is a room for observation between the pond and the refinery, rectangular in shape, with two domes, and two doors on each side, except for the southern side, which has one door. The doors are arched in the

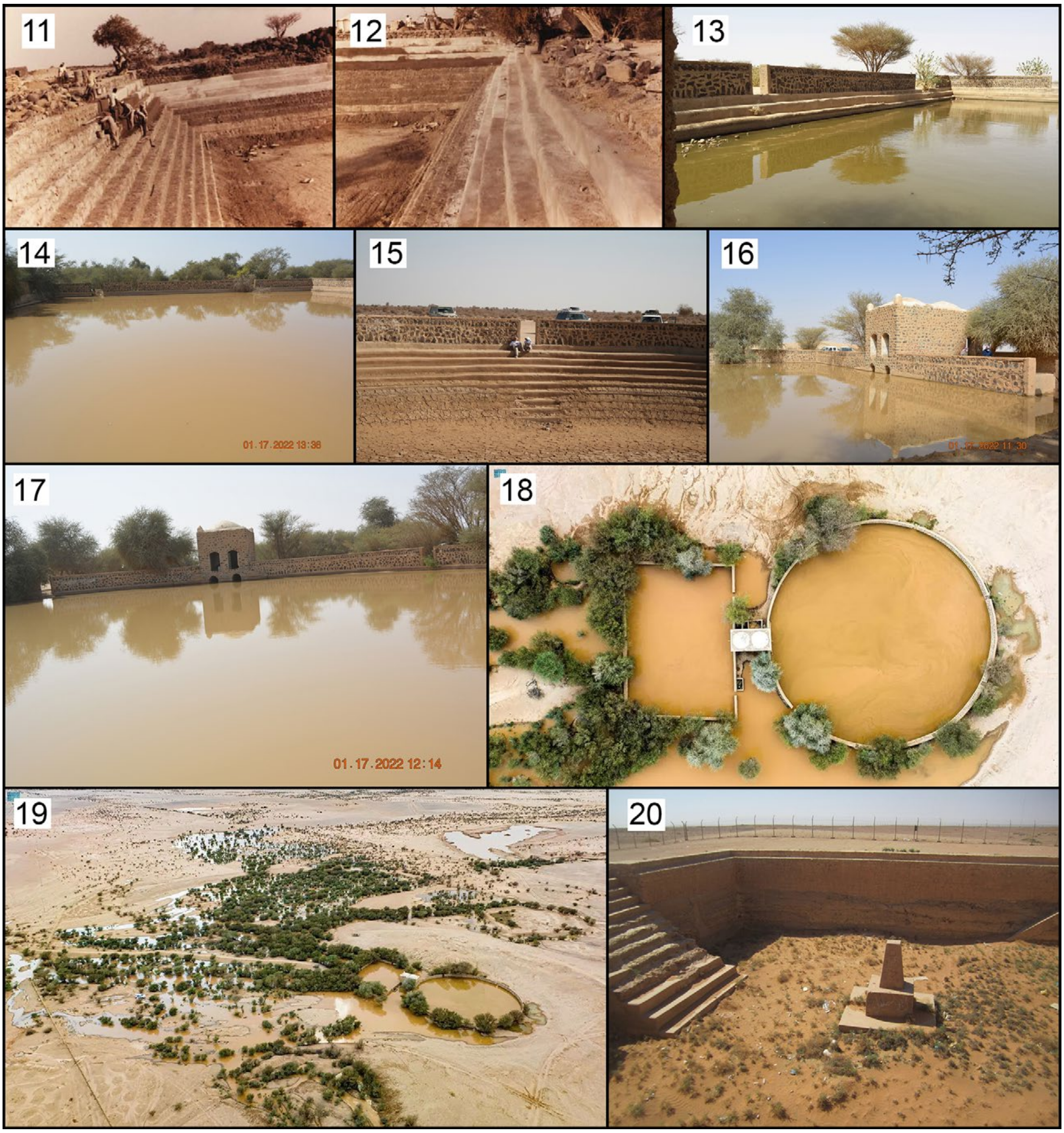

Figure 2. 11. Birkat Al-Aqiq showing original steps during restoration (7 June 1973). 12. Birkat Al-Aqiq showing the exposed original walls and restoration (7 June 1973). 13. Birkat Al-Aqiq in full flood. 14. Birkat Al-Aqiq, Darb Zubaydah, in full flood. 15. Birkat Al-Kharabah showing steps from top to bottom. 16. Birkat Al-Kharabah showing filter tank and guard chamber above the sluiceway. 17. Birkat Al-Kharabah showing the round cistern with water canals and the guard chamber above. 18. Drone image of Birkat Al-Kharabah showing the filter tank and main round cistern. 19. Drone image of Birkat al-Kharabam and its surroundings after heavy rain. 20. Birkat Al-Jumaymah showing walls and staircase, Northern District, Saudi Arabia.

style of early Islamic architecture. The area of the room is 9 x 5m, and its ceiling is 12m in height. The water is transferred from the refinery to the main pond when the amount of water increases through two drainage holes below the surface of the room floor. This water structure is unique in the Arabian Peninsula. (**Figures 2.15 to 2.19**).

As mentioned above, the restoration and reconstruction works of water structures in Al-Aqeeq and Al-Kharaba were not conducted using archaeological or conservation techniques that guarantee preservation of architectural details. There was also no proper selection of building materials that are compatible with the nature of the original building material. In addition, the restoration work was not preceded by technical and engineering specifications and careful documentation before and during cleaning, restoration, and reconstruction. We also noted that restoration of the ponds did not consider the surrounding environment as bulldozing work extended to the remains of old buildings and foundations, including bulldozing of some wells and other ponds along Darb Zubaidah with the aim of benefitting from the building materials.

In light of our observations of these works, an immediate report was prepared for the Ministry of Education in the same year (following a long field trip along Darb Zubaydah from Iraq to Makkah), and a technical team was formed from the Ministry of Education and the Ministry of Agriculture. The issue was eventually presented to the attention of the late King Faisal who stated that, 'If the Ministry of Agriculture needs to build ponds on Darb Zubaydah, it has to build new ponds and leave the ponds on Darb Zubaydah as they are'.[4]

In light of this directive, the Ministry of Agriculture began constructing modern ponds close to the old ones. We noted that implementation of the new ponds by the Ministry of Agriculture were conducted in an indiscriminate manner in terms of the construction technique. This is because the construction companies undertook bulldozing work for the old facilities close to these ponds, as well as bulldozing nearby streams and valley streams, in an ill-considered manner. Also, the new ponds were not designed to keep water from leaking, as the stone blocks were built on retaining sand walls. Cracks occurred in the sides of the walls and floors of the ponds, which led to the loss of large amounts of water in a short time compared to the old ponds that remained in a good condition.

For example, some Western travellers narrate that the amount of water Al-Jumaimah Pond had in 1910 was sufficient for approximately 12,000 persons for several days and that the number of tents erected near the pond in 1915 amounted to 3500 (Leachman 1911; 1914; 1917: 76-88). (**Figures 2.20 and 3.21**). There were other ponds similar to Al-Jumaimah Pond in the northeastern part of Darb Zubaidah, which remained in their original condition and had specific architectural and engineering details, including Al-Thulaima Pond. (**Figures 3.22 and 3.23**).

It was possible to develop this project, avoid the negative aspects of construction work, undertake maintenance of these ponds before the rainy season and during floods, and inform beneficiaries of the optimal way to benefit from pond water in a healthy manner, clean ponds immediately after the end of the rainy season, and combat epidemics resulting from muddy sediments. In fact, restoring and repairing the old water structures on the Darb Zubaydah is very important as the ponds, wells, dams, and canals can bring great benefits. This work will serve the Bedouins and those living along the road and make the surrounding environment more beautiful and attractive. The availability of water in these facilities, including wells, ponds and dams, will lead to increasing vegetation and serve in attracting birds and wild animals which will grow and reproduce.

[4] A recorded meeting with His Highness Prince Khalid bin Fahd bin Khalid, Undersecretary of the Ministry of Education, Member of the Supreme Council of Antiquities, on the occasion of the first Saudi Arabia Antiquities Forum (18-20 Safar 1439 AH / 7-9 November 2017 AD).

Al-Rabadha, the Islamic City on Darb Zubaydah (A Model for Water Conservation)

The city of Al-Rabadha is a unique model in its reliance on water resources (**Figure 3.24**). It was described by some Muslim geographers, including Ibn Rustah who said, 'It is a place with a lot of Bedouins, ponds and wells. The house of Abu Dharr Al-Ghifari and his grave are there. It has a mosque, and it is one of the ancient villages of pre-Islamic times' (Ibn Rustah 1892: 179). Qudamah ibn Ja'far said, 'It has plenty of waters, and there is a pulpit in it'(Qudama 1981: 80). Water is the essence of life and a factor in the emergence of civilizations when it is abundant. It is also a cause of fall of civilizations when it is rare. That is why the geographer Al-Maqdisi described Al-Rabadha when he saw it after being destroyed by the Carmathians, as having, 'undrinkable water and a place in ruins'.[5] After the destruction of Al-Rabadha, Yaqut Al-Hamawi said, 'It was one of the best places on the road to Makkah' (Al-Harbi 1969: 326-328).

Al-Rabadha depended, in the life of its residents and the caravans of pilgrims, on multiple sources of drinking water, industry and agriculture. These resources include the following:

- Seasonal rainwater and floods
- Underground water
- Ponds and water basins
- Wells
- Streams and springs in the surrounding geographical area

Al-Rabadha has two large ponds to preserve rainwater and floods. The first to the east of the archaeological site and the second to the north of it, 2km away. This is consistent with what Al-Harbi reported, 'Al-Rabadha has two drinking water ponds, one of which is round and has a refiner, and the other, which is less than one mile away, is square' (Yaqut al-Hamawi 1955-1957: Volume 3, 1091). The following is a brief description of these two ponds:

[5] Al-Maqdisi, (196), *The Best Divisions in the Knowledge of Regions*, 108.

Figure 3. 21. Birkat Al-Jumaymah half full of rain water. 22. Birkat Al-Thulaymah during cleaning, northern section of Darb Zubaydah. 23. Birkat Al-Thulaymah in full flood. 24. Map showing excavated areas at Al-Rabadhah. 25. The round cistern filled with rain in Al-Rabadhah Islamic city. 26. The circular birkah in Al-Rabadhah during the dry season. 27. Two stairways in opposite directions leading to the bottom of the circular tank at Al-Rabadhah. 28. Water channel from the rectangular filter tank to the main cistern at Al-Rabadhah. 29. The internal wall of the circular cistern at Al-Rabadhah. 30. The square cistern to the north of Al-Rabadhah - showing internal butresses to resist the pressure of floodwater.

The Round Pond

The round pool is characterized by its large size and regular round shape, with a diameter of about 64.50m, and its maximum depth at the plaster floor is 4.70m. The pond was built with limestone cut into varying sizes and laid with mortar. The walls and floors of the pond were coated with a thick layer of plaster. The wall of the pond is approximately 2m thick.

The pond is fed with water through a refiner adjacent to it from the west. This refiner is rectangular with an area of approximately 55 x 17m and is about 3.15m deep. Flood water reaches the refiner through two entrances. The first is in the northeastern corner and the other in the southeastern corner, and each of which descends to the floor of the refiner with a gradual slope. A dam extending to the southeast in a zigzag manner helped deliver water to the refiner. There was another dam northwards for the purpose of controlling the valley's water in the case of torrential flows. When the refiner is full, water moves through an upper estuary descending to the floor of the pond in its southern part and branching between the refiner and the main pond. The pond was also provided in its southern part with a staircase branching into two sections descending from a main terrace to the bottom of the pond. The number of steps of the staircase descending towards the west along the wall of the pond is 11. Although this pond was built more than 10 centuries ago, it is still in a good condition, save for some cracks in its interior walls and collapse of its plaster layer.

Mud deposits have accumulated over years inside the pond and the thickness of which amounted to about 2m. To know the depth of the pond and the refiner as well as the nature of its floor, four excavations were made in the refiner and five around the wall of the pond and at the mouth. It was found that the floor was covered with a thick, smooth layer and that there was a cement screed where walls of the refiner and the floor meet, to prevent any water leakage and ensure that the water remains inside the pond and refiner for a long time. The capacity of the pond when filled with water is estimated at approximately 14250m^3, which is a huge quantity of water sufficient for a large number of travellers and residents with their animals for many months (Al Rashid 2023: 90-91; 2018: 316-317). (**Figures 3.25 to 3.29**).

Square Pond

This pond was built in a relatively remote place, about 2km north of the residential area, and its dimensions are approximately 26 x 26m. It was built with cut limestone. The remains of the plaster layers are still clearly visible on its interior walls.

The pond was provided with two main intakes, the first in the northeastern corner and the second in the southeastern corner, both of which descend into the pond with a gradual slope. The pond was provided with stairs along the southern intake. The northern intake of the pond is connected to a dam located in the middle of the valley to intercept rainwater and floods to flow into the pond. To ensure that the pond can maintain water, its walls were supported from the inside by semicircular arches.

Although mud deposits cover the floor of the pond, its current depth is approximately 1.50m. It appears that this pond was built in this location to serve the travelling pilgrims and other people, and to allow them to obtain water conveniently and easily without disturbing the local residents and reduce pressure and crowding on the larger round pond. These two ponds are important examples of the engineering techniques in which Muslims excelled in the early Islamic eras. The Darb Zubaydah also represents a clear model of this development and experience in engineering water facilities and Muslims built dozens of ponds of this type along the road from Kufa to Mekkah (Al Rashid 2023: 92; 2018: 320). (**Figures 3.30 to 4.31 and 4.32**).

Water Wells

Since the establishment of Al-Rabadha, its residents have relied on well water. It seems that the number of wells has increased with the expansion of the size of the residential city. Al-Harbi reports that Al-Rabadha had many wells. He identified only 13 of them, some of which are equipped with watering basins (Al-Harbi 1969: 328). However, all of these wells have disappeared, except for one well that still remains near the Western Mosque, of about 14m depth. The lower parts of the well were gouged into the rock layer and covered with stones. We noticed the remains of the buried wells throughout the archaeological site, which are low circles below ground surface. There are also remains of old wells in the northeastern and southeastern parts. It appears that some of these wells were excavated years ago for the purpose of reclaiming them, but to no avail (Al-Rashid 2023: 93).

Water Storage Tanks: Residential Areas

In addition to the previously mentioned water resources, archaeological excavations revealed a new technique of preserving water inside the houses of Al-Rabadha. We have not yet found this technique in any of the excavated archaeological sites, to our knowledge, in Iraq, the Levant, Jordan, and other regions where early Islamic cities emerged. Using this technique, the residents of Al-Rabadha relied on storing pure water inside their homes in underground tanks dug and built

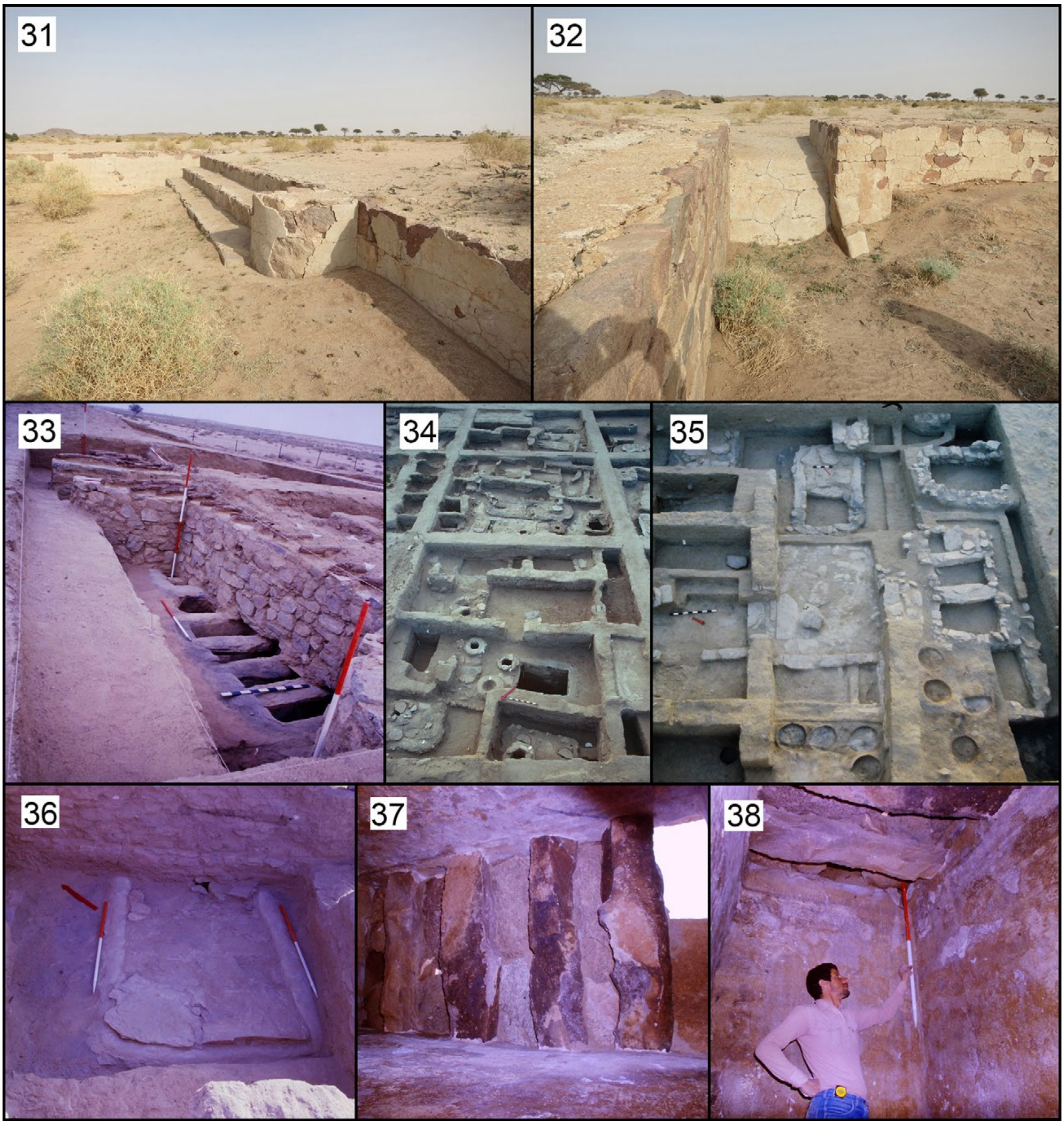

Figure 4. 31. The steps of the square cistern to the north of Al-Rabadhah with supporting round buttresses. 32. The water channel in the corner of the square cistern north of Al-Rabadhah. 33. The first discovery of underground water storage at Al-Badhah under the main wall of the palace (A) (1979). 34. Excavated section in the residential quarter of al-Rabadhah showing various underground water storage tanks inside rooms and open yards. 35. Underground water storage tanks some with intact roofs. 36. Intact underground water storage tankss. 37. Interior of underground water storage tank looking up towards the roof. 38. The inner walls of a tank covered with gypsum plaster.

in an ingenious engineering manner below the surface of the floors of the rooms and courtyards. The tanks are about 2m length on average, 2m depth and about 1.50m width. Some of these tanks are much larger, and each era also had its specific tanks.

After the tank is dug, stones were laid on its floor, some on the soft ground and others on the rocky layer. The walls and floor of the tank are then covered with a thick layer of plaster mixed with crushed gravel and ash. The layer in contact with water is softer to prevent water leakage after filling the tank with water. The floor of the tank is usually slanted on one side, with a slight depression on that side, in order to facilitate scooping water and cleaning the tank. The upper edges of the tank end with an outward frieze on which slabs of long stone made of granite or basalt rock are fixed. These stones are arranged along the width of the tank and fixed with strong mortar. The openings are covered with smaller stones and a light layer of mortar mixed with gravel is placed on the surface of the upper tank to prevent sand and insects from getting into the tank. Each tank is provided with a nozzle on the lower end to pull water when needed, with a tight cap covering this nozzle. The upper floors of the tank are at the same level as the residential floor and there were likely two methods of filling these tanks with water:

The first was by installing black stone pipes in the corners of the rooms so that they receive rainwater falling on the roofs of the houses, which runs through these pipes to the floor tanks. The second is that the residents of Al-Rabadha may have benefited from the numerous wells outside the residential homes. Water was poured into canals in which water ran, and emptied through stone pipes that were usually at a lower level than the canals. It is also likely that water was manually transported from its various resources and then poured into these tanks.

The method of building tanks showed that they were built individually within residential rooms, with one end of the tank adjacent to the corner of the room. In other cases, the tanks were built in adjacent groups connected with overhead canals to drain water into the tanks. In many cases, water went through a filtering process before getting into tanks.

In any case, the underground reservoirs were not concentrated in one area, but are spread throughout all residential areas, particularly in areas (E) and (D). It has been possible to classify the reservoirs according to their era. Low reservoirs are the ones that belong to the early era because they are dug in virgin land, then ones that are found above the level of the archaeological layers of the first eras, and finally, the raised tanks are those that were built in subsequent stages above the level of the previous residential floors.

It should be taken into account that some ground tanks may have been used in two eras, and this is evident in Al-Qasr area (A) and area (E). The total number of floor tanks discovered so far is approximately 100, which indicates the importance and necessity of water for residents of Al-Rabadha, the pilgrims and others, and that water was the mainstay of this region (Al-Rashid 2023: 94-95). (**Figures 4.33 to 4.38**). It is also evident from the architectural style in digging and building tanks that the inhabitants of the Arabian Peninsula in general and the residents of Al-Rabadha in particular had distinguished experiences and skills in this field.

Conclusions - Practical Steps to Benefit from Old Water Structures

Due to the importance of the ancient water structures on theDarb Zubaydah, the Saudi Heritage Commission has taken several steps to maintain such structures, including the following:

1. The Darb Zubaydah has been approved for inscription on UNESCO's World Heritage list.
2. The Heritage Commission adopted a strategic plan to preserve the heritage of the Darb Zubaydah, including ponds, wells, landmarks and archaeological sites, restore them, and transform them into attractive sites for cultural tourism after rehabilitating and developing them.
3. The Heritage Commission is keen to collaborate with stakeholders from government entities, the private sector, and the local community in developing the Darb Zubaydah with all its facilities, especially water structures.
4. Intensifying research on the Darb Zubaydah and encouraging postgraduate students to research the engineering aspects of the road's structures, to learn more about the history, architecture, and water resources of the road.
5. The local community will benefit economically, educationally, and culturally from the activities held in areas through which the Darb Zubaydah and its branches pass.

Previous and current excavations resulted in the discovery of very important cultural landmarks such as Zabala, Faid, and Al-Rabadha. This is a model to follow in tourism development in the region. The interest in restoring the Zubaydah ponds in accordance with the standards approved by UNESCO will revive these ponds so that they can constitute an important resource for local inhabitants, animals and wildlife.

Finally, there is no doubt that the Heritage Commission in the Kingdom of Saudi Arabia has a vision of benefiting from the experiences of other countries in preserving ancient water structures and rehabilitating them, after the manner of Oman, Yemen, Jordan, Tunisia, Turkey, Spain, Portugal, and other countries.

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Chapter 7.
Irrigation Systems in the Iraqi Western Desert: Abu Jir Springs Line as a Case Study

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Introduction

This paper focuses on the springs of Abu Jir and the irrigation systems around them. The Iraqi Western Desert represents two-thirds of Iraq and is part of the arid and semi-arid climate region, as its annual rainfall is less than 100mm. Six main geological periods are exposed in the Iraqi Western Desert, forming twenty-three geological formations. One geological formation belongs to the Permian, four formations from the Jurassic, eight from the Cretaceous, and nine from the Tertiary. Carbonate rocks dominate the lithology of the exposed geological formation, especially the Tertiary one, which has some marl, sandstone, and claystone layers. In addition to carbonate, some clastic lithology is in the Cretaceous and Jurassic. This diversity in lithology has resulted in the forming of geomorphological features, including sinkholes, valleys, plateaus, depressions, hills and cliffs (Sissakian and Faiyadh 2024). It mostly has rock surfaces and no dunes. Several natural springs and oases were developed alongside the boundary between the desert plateau and the Mesopotamian floodplain. This boundary or strip is locally called the Abu Jir lineament, and the associated springs are called the Abu Jir springs. The discharge from smoothly east-dipping Palaeocene–Eocene limestone geological formations occurs where groundwater channels overlap the ground surface or groundwater flow is forced to the surface by restraining aquitards (**Figure 1**) (Webb *et al.* 2024).

Iraq lies in the heart of an area traversed by humans coming out of and returning to Africa and across Eurasia since the Pleistocene (c. 2.58 million to 11,700 years ago). The earliest inhabitants of the western Iraqi desert can be dated back to the Stone Age period, as several archaeological surveys have highlighted the potential for the discovery of Palaeolithic sites and the preservation of Pleistocene landscapes in this desert (Voute 1957; Wright 1966; Schuldenrein 2015). Various lithics belonging to the Stone Age have been found in different places in the desert, including some at the Abu Jir Springs, confirming this potential. The floodplain was potentially habitable near these springs between the eleventh and early eighth millennia BCE. (Altaweel *et al.* 2019). People occupied some of these springs during the Sasanian Period (third to seventh century CE [all dates are CE unless otherwise specified]). Occupation continued during the Islamic Period (seventh to eigheenth-century) (Al-Mayali 2009), and traditional cultivation has still been undertaken in this area into the 21st century, although it is under threat due to climate change. However, several archaeological mounds in the area have not been fully excavated and might contain remains of older Sasanian and Islamic occupations (SBAH 2019).

Many travellers and orientalists, such as De Goeje (1889) and Musil (1927), mentioned certain Abu Jir Springs and described lifestyles there (Al-Mayali 2009). They pointed out that wheat, barley, and other seasonal vegetables were the main crops that grew on the farms. Date palm trees were the main trees that grew around these farms, and other fruits, such as pomegranates, grapes, and figs, were grown in the palm tree gardens. In these springs, people dug canals, managed the water, and reclaimed land to farm it. As people could only irrigate their farms using gravity irrigation, the shape, size, and direction of the farms were mainly controlled by the topography; however, the springs' discharge and the water quality controlled the type of crops.

The archaeology of irrigation systems and water infrastructure in Southern Iraq

During the Holocene, the southern region of Iraq had and continues to experience an arid climate with irregular and limited rainfall patterns of around 100-200mm (Hewett *et al.* 2022), necessitating alternative crop cultivation methods that rely on river water.

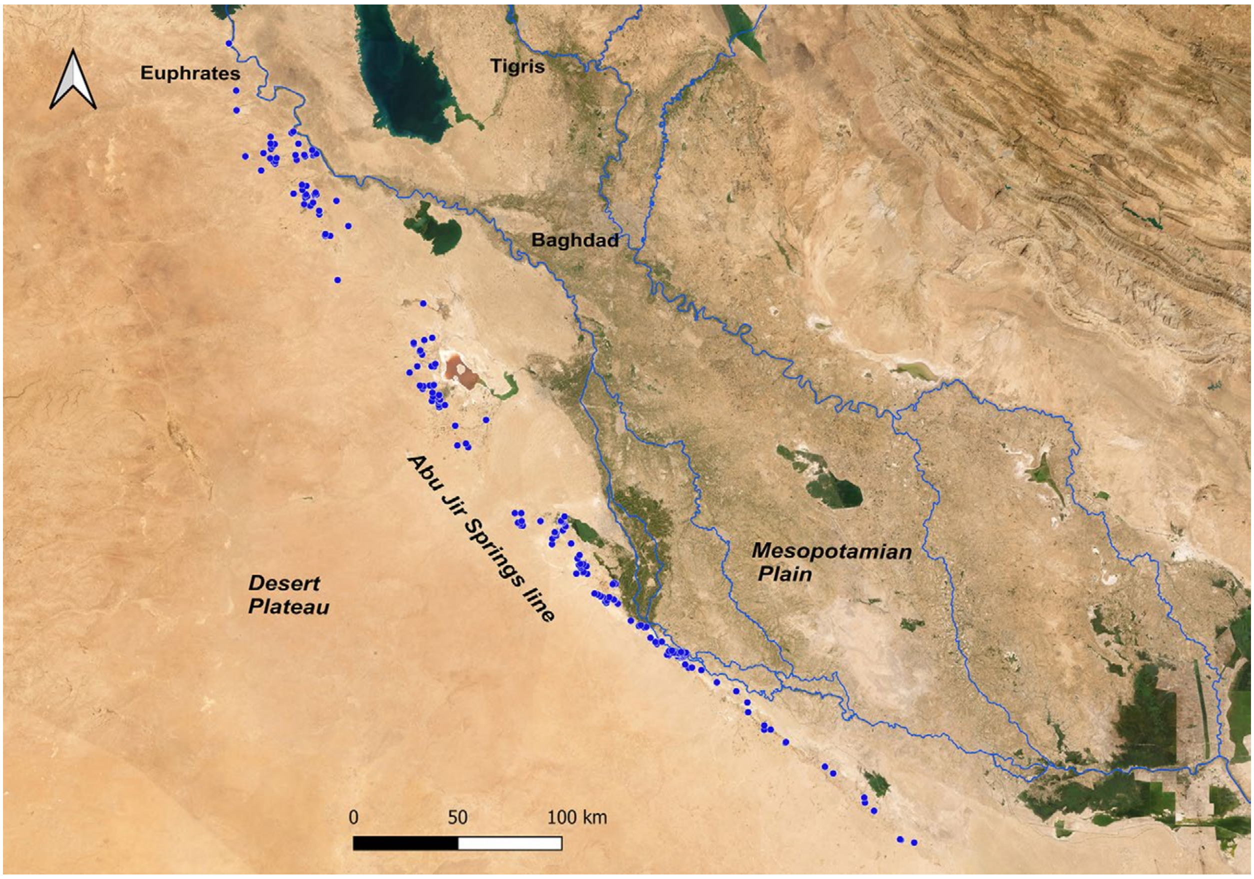

Figure 1. Location map of the Abu Jir Springs line between the floodplain of Mesopotamia and the Iraqi Western Desert. Maps Data: Google, Landsat/Copernicus Data SIO, NOAA, U.S. Navy, NGA, GEBCO

Constructing canals to divert water from rivers for irrigating adjacent lands is a well-established technique deeply embedded in the floodplain occupation, and it can be as old as the Ubaid Period (Jotheri *et al.* 2025). One of the earliest irrigation methods seems to have involved gradually modifying or creating crevasse splays, fans of sediments deposited by channels forming from breaks in river levees (Buringh 1960; Wilkinson *et al.* 2015). These methods for digging and maintaining irrigation canals evolved over time, beginning with crevasse splay modification in an early period back to at least the 5th millennium BCE (e.g. see recent dating evidence, Forti *et al.* 2022) and ranging to canal networks spanning hundreds of kilometres during the Sasanian Period, as they were passed down from one generation to the next (Wilkinson *et al.* 2015). Significant Sasanian canals included the Nahrwan canal and a set of transverse canals (Christensen 1993). Most Sasanian irrigation canals in the Mesopotamian floodplain, such as the Nahrawan, Dujail, Isan, Sarsar, Malik, Kutha, Surat, and Niel, are well preserved and can be identified via remote sensing and on-site inspection (Jotheri 2016). Archaeological sites along these canals often show Sasanian occupation and are occasionally older. Additionally, some of these sites have Islamic occupation covering them, indicating that the canals were reused or continued to be used during the Islamic period.

The Islamic period

By the early Islamic period, northern and southern Mesopotamia were both cultivated with large-scale, reticulated canal networks. Although rainfed cultivation is possible in parts of northern Syria and Iraq, yields would have been more reliable with the application of irrigation technology. Water management systems supported the early Islamic empires across Mesopotamia (Rayne 2025), perhaps driven by growing urban centres (Kennedy 2011). Some scholars suggest that southern Mesopotamia's floodplain was already extensively canalised and cultivated during the Sasanian Period and started to decline during the late Sasanian and early Islamic period, reaching its least cultivated condition in the 9th century (Kennedy 2004; Christensen 1993; Jotheri 2016; Allen and Heldring 2022). Conflict and disease in the 5th to 8th centuries likely reduced available labour and disrupted irrigation (Rayne 2025), possibly

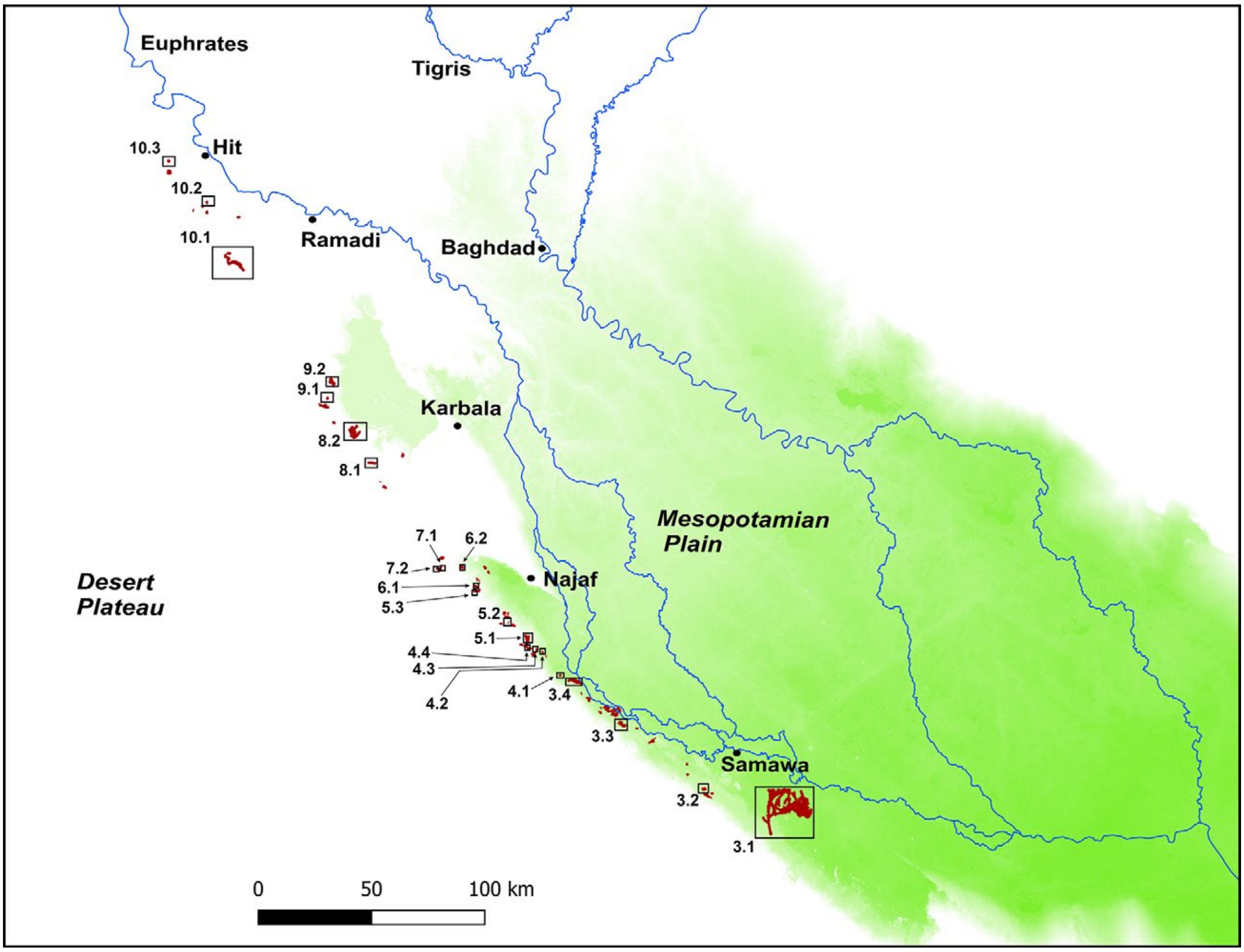

Figure 2. Topographic SRTM map showing the twenty-two springs and associated farms.

in the long term (Christensen 1993). However, there is evidence that investment in irrigation continued in the early Islamic period, comprising both the reuse of older systems (e.g. Decker 2009; Verkinderen 2015) and, in some cases, the construction of new canals in order to bring formerly marginal land into cultivation. Incentives such as tax breaks/land ownership policies were offered by the state at this time to encourage new cultivation (Kennedy 2011).

A set of earthworks close to Basra, which seem to represent canal and field systems, were recently scientifically dated to the 9th-13th centuries, with OSL results falling within the early Islamic period (Brown *et al.* in press), but radiocarbon dates from shells gave earlier dates of the 1st-5th centuries. Some irrigation methods, such as the *qanat* system, were increasingly used in Mesopotamia during the Islamic period (Avni 2018; Rayne 2025), but not inside the floodplain as it requires high land with proper dipping so the groundwater can move inside the tunnel. In Iraq, *qanats* are most numerous in the north (Lightfoot 2024), but several *qanat* systems have been reported in the floodplain's boundary, such as the Zagros mountains and the Iraqi Western Desert. A *qanat* was found near the Persian-Abbasid site of Ukhaidir (Lightfoot 2024). *Qanats* at Samarra may also date to the Abbasid period (Lightfoot 2024). Archaeological remains of bridges from both the Sasanian and Islamic periods are still standing, such as the Harba dams in Baghdad and Qantarra Kiri Siada in Karbala (Petersen 2025).

Methodology

A systematic remote sensing and GIS (Geographical Information Systems) survey has been carried out in the study area, a well-established method for recording archaeological sites, including water management systems in Iraq (e.g. see Hammer *et al.* 2022a; Hammer *et al.* 2022b; Jotheri *et al.* 2025). Digitising was undertaken using high-resolution Google Earth, Bing Maps and CORONA satellite imagery. CORONA satellite photography, developed from the United States intelligence programme of satellite surveys from 1959 to 1972, was obtained from USGS and georeferenced using QGIS. The springs, canals, farms, and fortresses were digitally traced, and QGIS shapefiles were created. Twenty-two spring locations in the Abu Jir Springs line have been selected for this study, with farms around them as they had fresh or mild water and fertile land (see **Figure 2** for locations and **Figures 3.1 to 10.3** for each one of them singly.) Ground-truthing field trips to several of these springs were carried out. Drone images of some of these canals and farms were taken, and interviews with local farmers were conducted. The irrigation canals and farms were traced, and separate maps were produced to show how the canals and farms were distributed around the springs.

The landscape of settling and farming around the springs

In the Iraqi desert, there are two main areas where fortresses can be found. One is the pilgrims' road between Kufa and Mecca, and the second is alongside the Abu Jir Springs line. Regarding the line of the Abu Jir springs, twelve forts were mapped they are, from the south to the north: Abu Ghar, Nabaa, Al-Qsair, Ayn-Sayed, Shallal, Aqlah, Al-Rahabah, Madhlum, Al-Ukhaidir, Bani Muqatil, Al-Aqiser and Al-Bardwil (a more detailed description of the archaeology around Abu Jir Springs will be given in a future publication). However, travellers, orientalists, historical texts, and topographic maps mention other fortresses that cannot now be found on the ground. This is because they were demolished because of modern urban development or were made from unbaked bricks that were not capable of resisting weathering, and so they disappeared. The size, design, building materials, period and purpose of construction differ from one fortress to another.

Five main reasons behind building these fortresses alongside the line of the Abu Jir Springs can be highlighted: military, agricultural, trading, rest and religious. From a military point of view, the rulers of southern Mesopotamia built fortresses and trenches between the floodplain and the western desert to protect the floodplain towns and farmers from any attacks that usually came from the nomadic people, who were violent groups or tribes, who lived in the desert (Spring 2015; de Gruchy *et al.* 2021). For farming purposes, the landlords around the springs built forts in the farms so they could live in them and securely store their grain and other produce (Al-Mayali 2009). Some forts in this area were trading centres between the floodplain farmers and nomadic shepherds, as the nomadic tribes usually exchanged livestock for grain and dates (Susa 1983). Forts were also used for relaxation by rulers and wealthy families of southern Mesopotamia, who saw some areas in the western desert as good places for hunting and healing (Schmidt and Finster 1976). As for religious purposes, the Nestorian Christians built fortresses as places of worship in abandoned areas and near caves and springs (Fujii *et al.* 1998).

For example, the Nestorian Christians constructed Al-Rahabah, Al-Aqiser and Al-Bardwil forts in the early first millennium (SBAH 2009) as they thrived and expanded during this Period (Rice 1932; Toral-Niehoff 2009). In general, fortresses are a common feature across the desert of the Arabian Peninsula, where people use them for temporary rest, settlement, trading centres, places of warships, and for military purposes, and border security (de Gruchy 2021). Most oases, roads, religious places, and trading places in the desert between Mesopotamia, the Levant, Mecca, and Yemen have fortresses, as people typically travel between these places. The large springs and farming land required some more developed methods of water management, such as feudal systems; for example, Ayn Sayed Spring (**Figure 3.1**) was run by a feudal system; in 1869, Abdulla Al-Assaf migrated to Iraq from Saudi Arabia (Al-Mayali 2009). He was from a wealthy Al-Qassim family who owned an oasis called Al-Shaqah in Al-Qassim Province in Saudi Arabia. The family were well known for their feudal farming regime around the oasis. Therefore, when he came to control Ayn Sayed, he built a fortress close to the spring and started recruiting farmers from villages and towns with good farming skills. They dug an approximately 30km long central canal from the spring towards the fertile land east of the spring, between the Euphrates River and the western desert. The number of farmers and the cultivated land area grew fast until it reached around 60km^2; the main crops were wheat and barley, most of which were shipped to Saudi Arabia. Based on feudalism, peasants were not allowed to grow palm trees or build brick houses. The spring was known for its freshwater, which was rich in fish and a place for gazelles. Nine landscape features have been identified that characterise these springs.

Spring, canal, fortress and farm combinations

It is common amongst the identified springs to find fortresses or settlements associated with springs. There are also relatively long canals dug to take water from the springs to irrigate farms (for example, **Figures 3.1, 3.4, 6.1, 8.1, 8.2, 9.1, and 9.2**).

Grouped springs

People connected springs together to increase the amount of water required to irrigate their farms (for example, **Figures 3.3, 3.4, 4.4, 5.2, 6.1, 8.2, 9.2, and 10.1**).

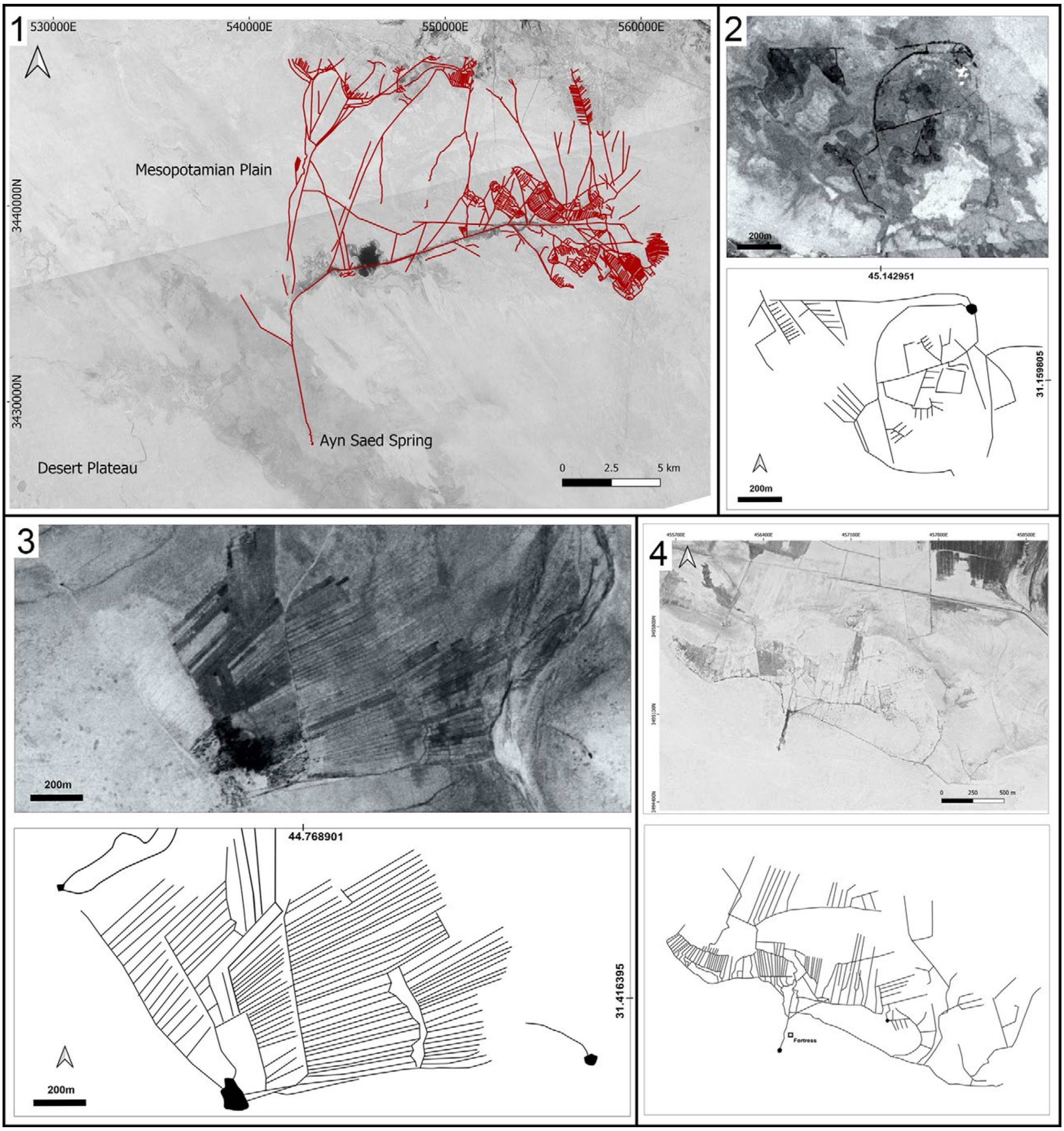

Figure 3. 1. Corona satellite image showing Ayn Saed Spring and the associated canals and farms. 2–3. Corona satellite images showing springs and their associated canals and farms. Bottom: the traced canal and farms. 4. Top: Corona satellite images showing Shallal Spring and its associated fortress, canals and farms. Bottom: the traced canal and farms.

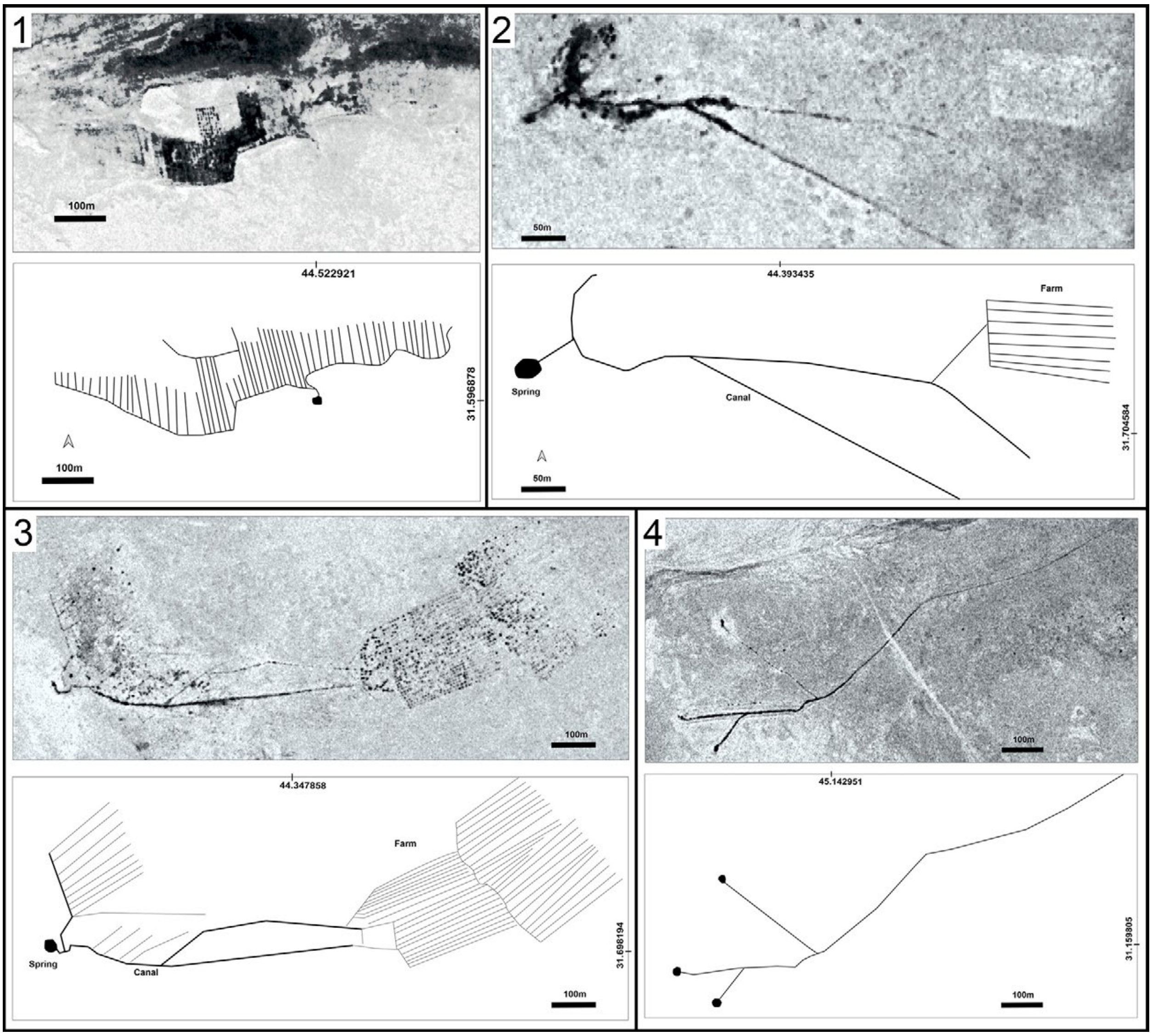

Figure 4. 1–4. Top: Corona satellite images showing springs and their associated canals and farms. Bottom: the traced canal and farms.

Grouped springs and qanat

When finding a spring to connect with another one was challenging, people tended to dig a *qanat* irrigation system to increase the amount of water to irrigate their farms (for example, **Figure 5.3**).

Comb-shaped farms

The familiar shapes of the secondary or tertiary small canals from the farm are parallel straight lines forming a comb-shape farm (for example, **Figures 4.1, 4.2, 4.3, 4.4, 8.1, and 9.1**).

Broom-shaped canals

Digging a relatively long irrigation canal from the spring to the farm made a broom-shaped canal (for example, **Figures 4.3, 6.1, 6.2, 8.1, 9.1**)

Single and multi-farms

Some springs have one farm, while others have multiple farms depending on that spring (for a spring with a single farm, see **Figures 4.1, 4.2, 5.3, 6.1, 7.1, and 10.3**); for multiple farms, see **Figures 3.1, 3.2, 3.3, 3.4, 4.3, and 9.1**).

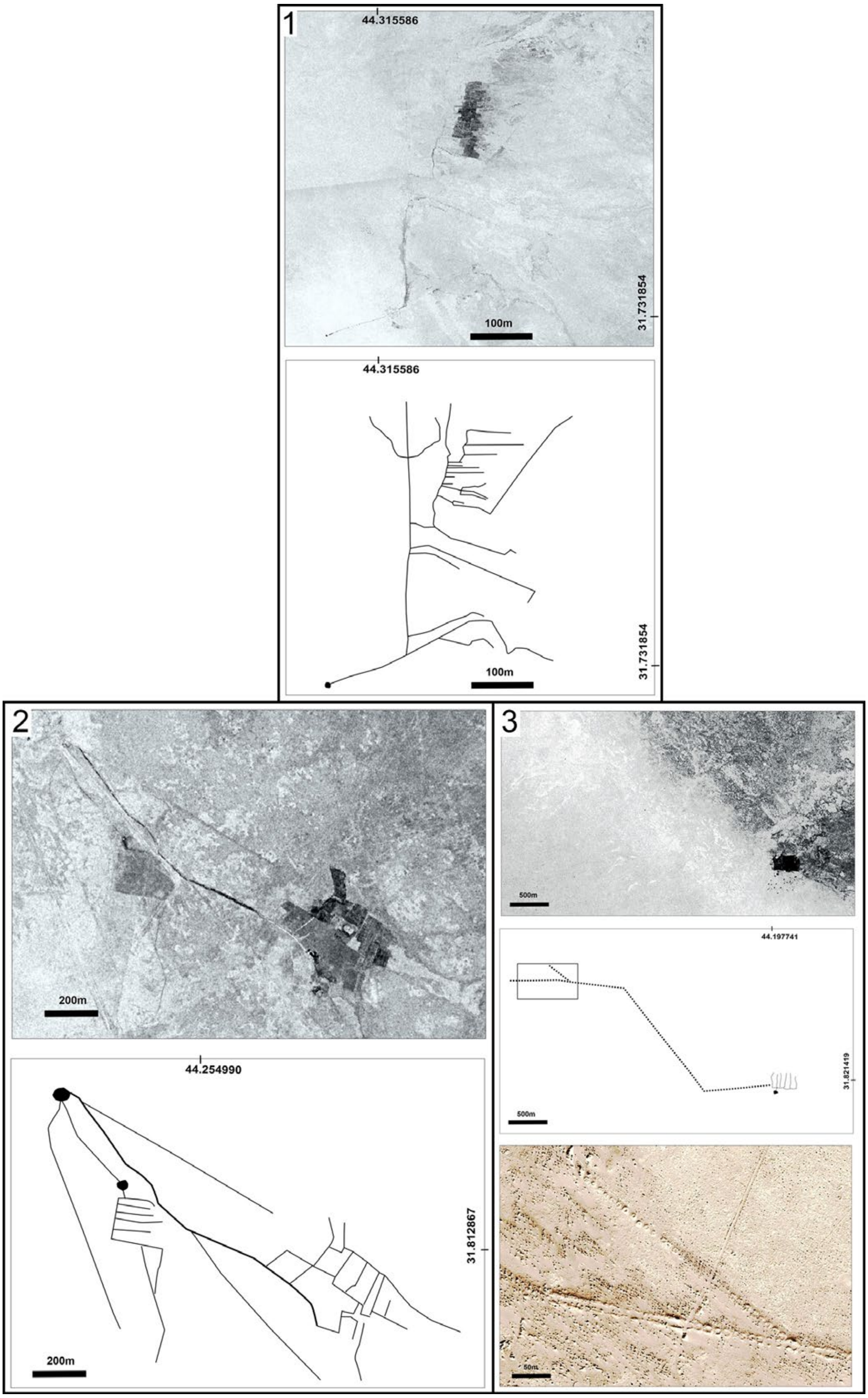

Figure 5. 1–2. Top: Corona satellite images showing spring and its associated canals and farms. Bottom: the traced canal and farms. 3. Top: Corona satellite images showing spring and its associated canals and farms. Middle: the traced canal, *qanat* and farms. Bottom: Satellite images form Google Earth showing part of the *qanat*.

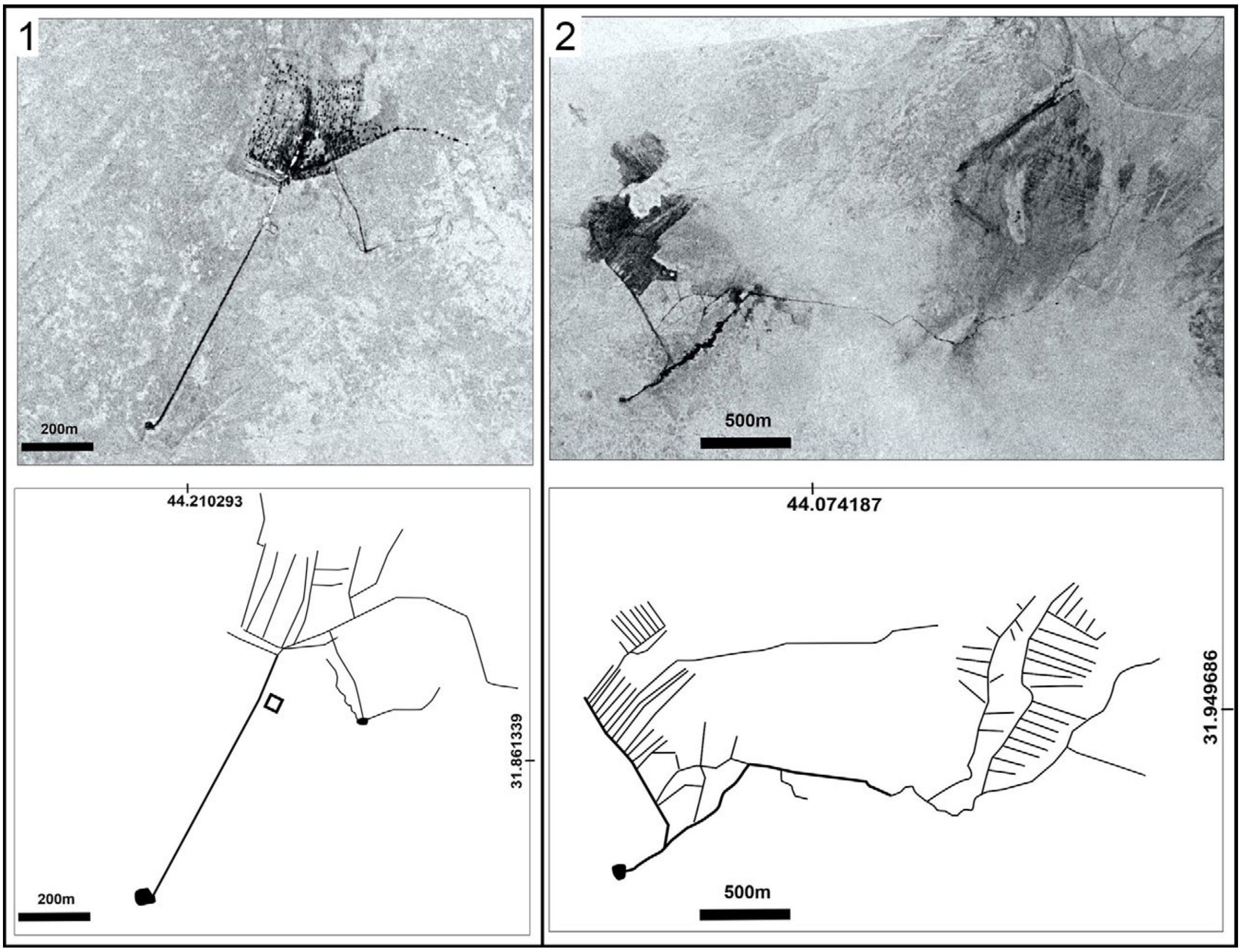

Figure 6. Top: Corona satellite images showing springs and their associated canals and farms. Bottom: the traced canal and farms.

One-sided farming land

Because of the topography, most springs could irrigate the lowest side of the spring (for example, **Figures 3.1, 3.2, 3.3, 3.4, and 4.1**) as people used gravity flooding irrigation methods and could drive water up to a higher elevation. However, there were occasions when springs could feed the surrounding area (such as in **Figures 7.2 and 9.1**), as the land around the spring was relatively flat.

Trial-and-error canals

Not every canal accomplished the purpose behind digging it; people sometimes dug canals from the spring but did not connect them to any farm. This might mean that the canal could not irrigate the land because of the topography or because the land was not fertile enough (for example, **Figures 4.2, 5.2 and 10.3**)

Draining excess water

Some springs produce water that exceeds the required amount to irrigate the land. This leads to letting this excess water run into valleys or rivers or forming lakes (for example, **Figures 3.1, 3.4, 8.1, 8.2 and 9.2**). Some of the largest springs, such as Ayn Sayed (**Figure 3.1**), Shallal (**Figure 3.4**), Ayn-Al-Tamir (**Figure 8.2**) and Al-Rahhaliyah (**Figure 9.2**), were able to irrigate farms with large areas (60km^2, 4km^2, 50km^{2,} and 7km^{2,} respectively) and relatively large human populations. However, other small springs could only host a household or two and a few hundred meters of farm area (**Figures 7.1, 7.2 and 10.2**).

Conclusions and next steps

The archaeology of river canal networks, *qanat* wells and tunnels, oases and springs' canal networks, waterwheel remains, hill terraces, and sea tidal canals and reclaimed marshes in Iraq represents a long period of human occupation. It demonstrates how people have

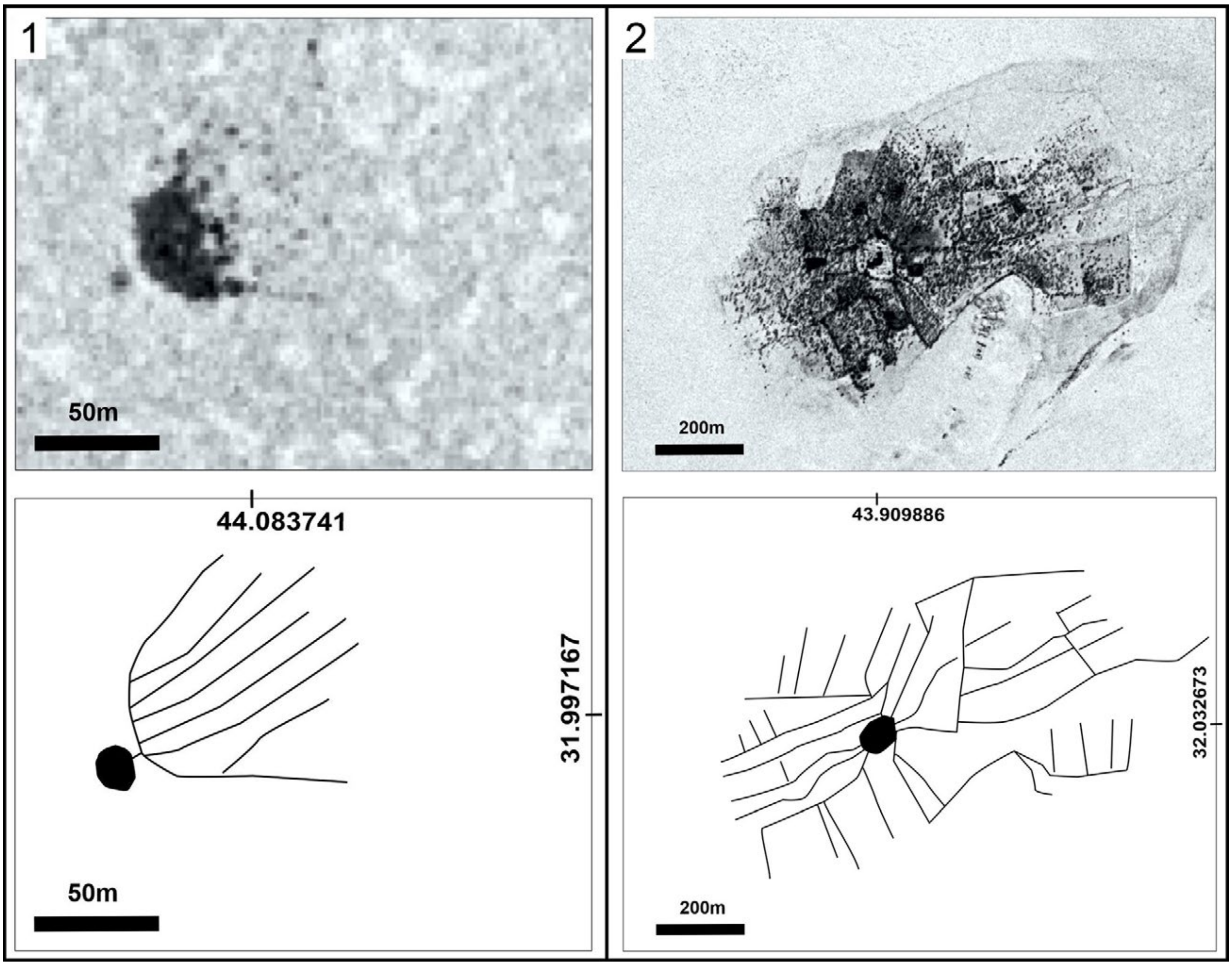

Figure 7. Top: Corona satellite images showing springs and their associated canals and farms. Bottom: the traced canal and farms.

historically modified and established the landscape to suit their needs. Based on the appearance of nearby sites, it is likely that some of the irrigation systems stemming from the springs along the edge of the western desert were constructed at least as long ago as the Sasanian period. Because there tend to be ideal hydraulic pathways for efficient water management in any landscape, the canals and field systems still visibly in use at the time of the CORONA images probably represent simply the latest phase in a long period of irrigation on the same alignments.

This paper presents the first detailed classification of the large area of springs surveyed as part of a set of interconnected studies led by the authors and their collaborators; we have also investigated the hydrogeological properties of the springs (Webb *et al.* 2024) and conducted a regional-scale remote sensing study (Cigna *et al.* 2024). Ongoing studies should prioritise archaeological investigation and scientific dating of sites of all types in this area before they are destroyed due to the impacts of climate change and modern development. The well-preserved and recorded diverse irrigation systems of the springs hold significant tourism potential. The irrigation system in the Iraqi Western Desert illustrates the oasis irrigation method, demonstrating how inhabitants utilised the flowing water from these springs to irrigate the fertile land surrounding them. Additional efforts are required to maintain the operation of these springs and oases and restore their irrigation system and community. Increasing the number of modern pump wells and extracting groundwater upstream will dry up the springs and potentially displace the surrounding communities.

Acknowledgements

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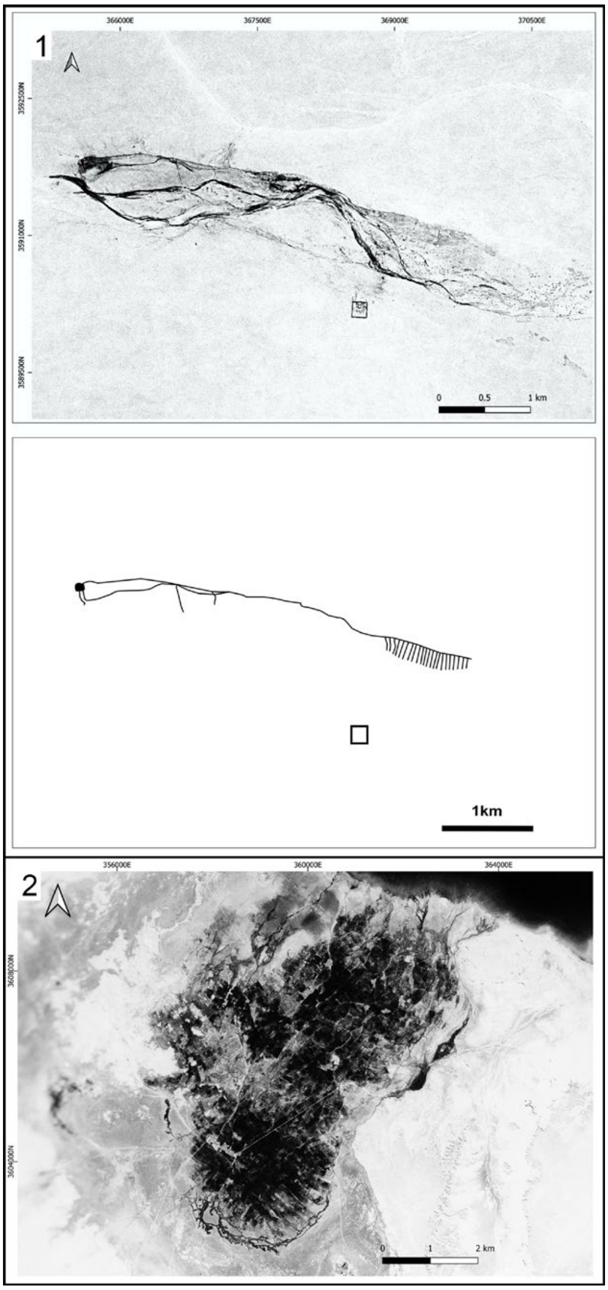

Figure 8. 1. Top: Corona satellite images showing spring and its associated fortress, canals and farms. Bottom: the traced canal and farms. 2. Corona satellite images showing Ayn Al-Tamir spring and its associated canals and farms.

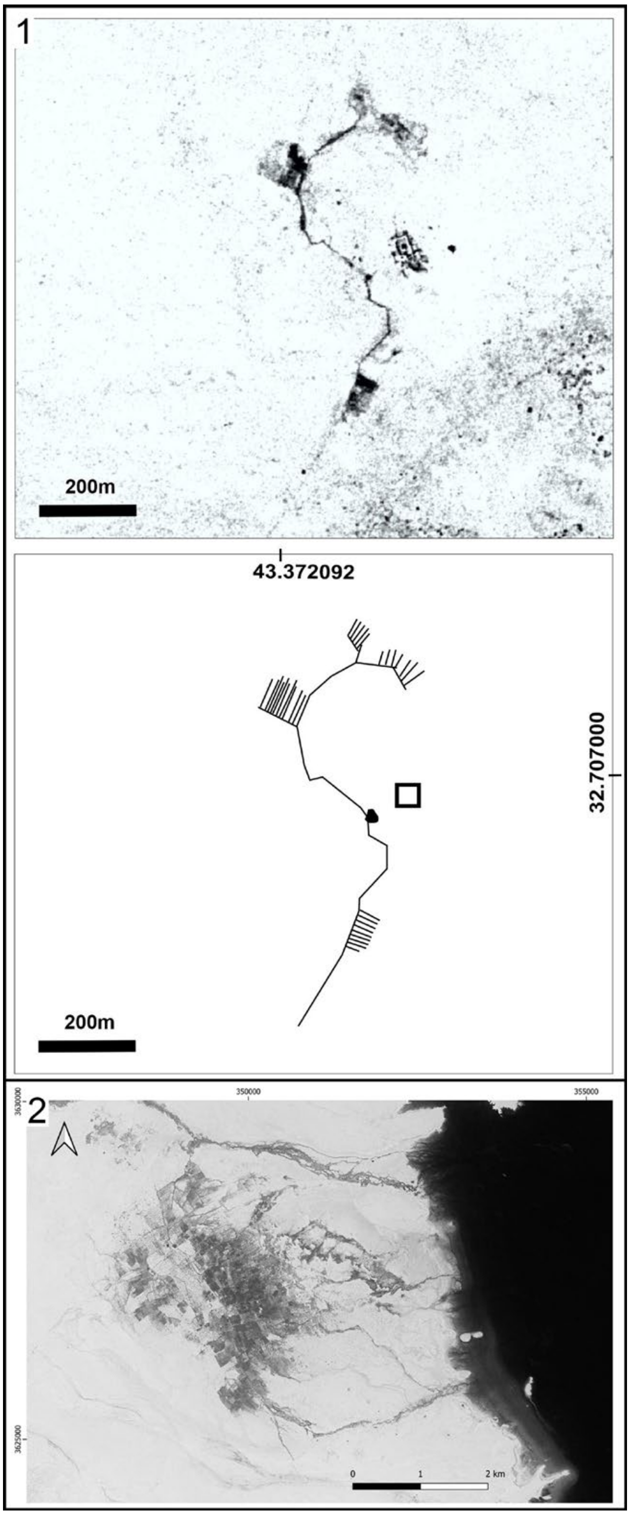

Figure 9. 1. Top: Corona satellite images showing spring and its associated fortress, canals and farms. Bottom: the traced canal and farms. 2. Corona satellite images showing Al-Rahaliyah spring and its associated canals and farms.

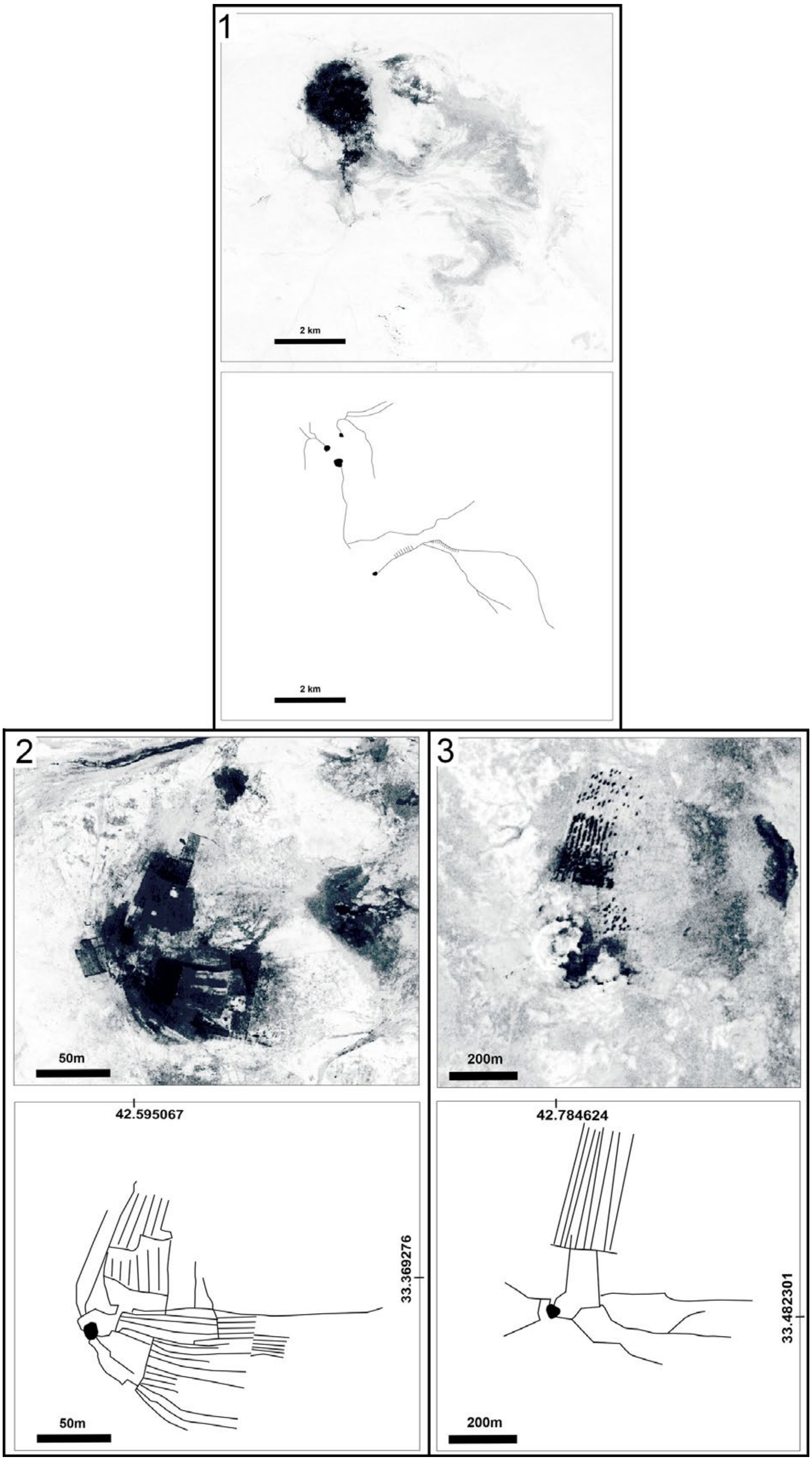

Figure 10. 1–3. Top: Corona satellite images showing springs and their associated canals and farms. Bottom: the traced canal and farms.

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Chapter 8.
Oasis Construction on Landscape Scale: How Ancient Runoff Irrigation in the Southern Levant Created Fertile Agricultural Terrace Soils

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Introduction. Terrace remains in drylands

Remains of ancient terraces are omnipresent landscape features in drylands of the Levant, but they are not always easily identified or understood. For example, the Negev desert is famous for its widespread remains of runoff-collecting terraces (**Figure 1**). These consist partly of small, weakly built walls, which mostly cross valleys (Type A according to Avni 2022), but partly include well-built, massive diversion dams (Type B according to Avni 2022). The Negev terraces were subject to systematic (partly experimental) research since the 1950s (Evenari *et al.* 1982), and Avni *et al.* (2019) recently published a summarizing overview about their history and potential purpose. It is important to note that Avni *et al.* (2006, 2019) consider the emergence of runoff-irrigated terraces in the Negev connected with a 'geomorphic window of opportunity', where erosion of Pleistocene desert loess had on the one hand largely removed soil from rocky slopes, thus creating sufficient runoff, but on the other hand only started to incise sediments in the valleys, so still enough was left to enable farming and soil collection by terraces. According to Avni *et al.* (2006, 2019), ancient land use in the Negev may have stopped and partly reversed soil erosion and desertification. It managed and took advantage of the strong runoff on barren desert rocks, which can emerge during the few, but often intense rains in such environments. This could be very relevant for the future, as global warming might lead to expanding deserts and related environmental conditions, but it is unclear whether the perspective offered by ancient land use is restricted to areas with specific geomorphic conditions similar to the Negev.

Figure 1. Terrace remains in the Negev desert, in the valley Nahal Haro'a, near Sede Boker. Person gives scale (photo. B. Lucke, November 2016).

Figure 2. The mountain Jabal Haroun near Petra. The white shrine of Prophet Aaron marks its top (photo. B. Lucke, September 2016).

Research on terrace remains in drylands has been rather limited, although environmental conditions are similar in various deserts (see Avni 2022 for a comparison of the Negev with Marmarica and southern Jordan). These limitations might partly be connected with the particular, technical challenges of field work and terrace investigation. For example, ancient terrace remains in the Petra region in southern Jordan were investigated by the Finnish Jabal Haroun Project (FJHP) which attempted to map terraces on the slopes of the mountain Jabal Haroun (**Figure 2**) near Petra (Kouki and Lavento 2013). There, remains of terraces show a great variety of shapes and preservation: they range from well-built, dam-like walls to petty stone lines which may, on the first look, hardly be identified as former terraces. Such small structures can easily be overlooked, and it needs a trained eye to identify these remains.

If small structures are not ignored, a great technical problem might arise as their number can be extraordinarily large, and their shapes and conditions extraordinarily variable, which is a challenge for any research strategy. Looking closely at Jabal Haroun, the whole mountain turned out to be covered by terrace remains (Kouki and Lavento 2013). Preservation states differ strongly, and a multi-period construction appears likely. This means that such terraces were constructed, maintained, repaired, and (partly) reconstructed possibly over a very long time, which makes it challenging to reconstruct this process. In addition, man-made terraces near Petra often made use of existing natural features, such as geological terraces (due to varying rock layer hardness), which adds to the complexity of the picture, and makes the drawing of maps an arduous task.

Many drylands which were earlier considered ‘empty’ of past human activities may in fact host a multitude of archaeological remains, in particular terraces. They were sometimes not identified because of their small and scattered shapes that can easily be confused with natural landscape features (Müller-Neuhof, 2016, 2017, 2022; Lucke 2023a; Lucke *et al.* 2024). What terrace remains in drylands have in common is that they slow down and/or collect runoff water (and sediments), that is, make it possible to utilize the water from occasional desert winter rainstorms. In the case of the Negev desert, Ashkenazi *et al.* (2012) found that ancient agricultural systems adapted to the landscape and can be typed accordingly. Bruins *et al.* (2019) calculated that gathered runoff in the Negev would increase water availability for plants in terrace soils from the given 50-100mm mean annual precipitation to effective 300-600mm, matching the moisture levels of most Eastern Mediterranean agricultural areas that are fed by winter rains. According to the experiments by Evenari *et al.* (1982), a runoff-generating area that is about 20 times larger than the cultivated field needs to be managed in order to gather sufficient irrigation water for desert cultivation.

The purpose of runoff-collecting terraces: not necessarily for cultivation

It is not a matter of course that dryland terraces served for cultivation: the debate on their actual use has not been terminated. For example, remains of possibly runoff-collecting structures can in some regions be identified on aerial views, such as in the basalt desert of north-east Jordan (Kennedy 1998), but it remained unclear how to interpret them. Do they represent an expansion of agricultural cropland into drylands, perhaps connected with periods of enhanced rainfall (Issar and Zohar 2004), or did they serve other purposes? Were they possibly connected with state-sponsored settlement expansions, e.g. along trade routes, which may not have had to rely on local subsistence economy, but were based on supplies of staple crops from better-watered regions (Shahack-Gross and Finkelstein 2008)?

In the basalt desert in north-eastern Jordan, an archaeological survey of man-made structures and off-site material culture was combined with soil analyses around the site of Umm el-Jimal in order to approach these questions (Lucke *et al.* 2019a). Results showed that small terraces clustered along wadis, catching runoff water from flood diversion channels, and were associated with circular stone structures. Although appearing as prominent features on aerial views, most of these terraces proved to be small structures on the ground which accumulated only limited amounts of sediments. Soil analyses of these sediments did not show indications of prolonged manuring, as could for example be indicated by elevated phosphorus content. As well, they were nearly devoid of material culture such as pottery.

In contrast, sediments in large open spaces within the ancient city of Umm el-Jimal were characterized by strongly elevated nutrient contents and connected with small channels from nearby cisterns. Therefore, it was concluded that the ancient inhabitants of the town probably grew vegetables and other crops within the city, where they could be irrigated by stored cistern water that had been diverted from floods in the valleys. In contrast, the surrounding hinterland was probably not used for cultivation, but for grazing, and for breeding animals, which could have provided local subsistence (Lucke *et al.* 2019a). The ancient name of the town is unknown, but such ancient practice would well match the modern name Umm el-Jimal, which means ‘mother of camels’.

Therefore, part of the numerous terrace structures visible on aerial views of north-eastern Jordan may not document ancient cultivation in the desert, but a sophisticated pastoral economy which exploited the available runoff water resources in order to improve grazing and the watering of herds.

Desert cultivation, including perennial fruit trees, based on runoff-irrigated terrace farming

It is still debated whether, when, and where runoff-irrigated terraces may have been used for the agricultural production of staple crops in desert margins. Historical written sources and archaeological studies in the Negev desert show that a vibrant agricultural economy existed there during the Byzantine period, but it is still not fully clear when the agricultural use began and when and why this system ceased to function (Avni *et al.* 2019; Avni 2020; Avni 2022; Tepper *et al.* 2020; Fuks *et al.* 2020). There is evidence that runoff-irrigated cultivation was practiced in the Negev desert from Hellenistic times onwards, but it is discussed whether it was already practiced during the Iron Age (or possibly even earlier) (Bruins and Jongmans 2012, Bruins and van der Plicht 2017, Shahack-Gross and Finkelstein 2017). In this context, Hunt *et al.* (2007) identified sediment units dated to the Bronze Age and later in Wadi Feinan in southern Jordan which were associated with terrace remains and signs of cultivation. In the Negev, it is unclear whether the runoff irrigation system declined after the Muslim conquest (Avni *et al.* 2019, Fuks *et al.* 2020) or may still have been well in use during part of the Islamic periods (Avni 2020).

From the Negev desert, results of experimental studies are available which reconstructed selected parts of the ancient agricultural system (Evenari *et al.* 1982; van Asperen *et al.* 2014; van Bommel *et al.* 2021). They found that the harvesting of runoff water would, in principle, function under present environmental conditions. It would not only make it possible to grow cereals but also permit perennial cultures such as fruit trees or wine. However, high manual work input is necessary as winter floods frequently damage terraces, so constant repairs and maintenance are required. The use of modern machinery is not possible due to small and irregular field sizes which makes it impossible to compete with modern agricultural world market prices. As well, the floods bring not only water, but also sediments, which accumulate behind terrace walls. This makes it necessary to build them slowly, but steadily higher in order to preserve their water-collecting function.

The accumulation of sediments behind the terrace walls makes them a potential archive of aeolian dust deposition. As nearly no natural aeolian sediment deposits dating to the Holocene were identified in the southern Levant, a project investigated terrace sediments in the Negev desert and in southern Jordan, with a focus on their potential role as late Holocene dust traps (Lucke and Bäumler 2021). The limestone-dominated Negev and sandstone-dominated mountains near Petra in southern Jordan were selected for the project as this permitted comparing very different geologies and geomorphology. Unexpectedly, it was

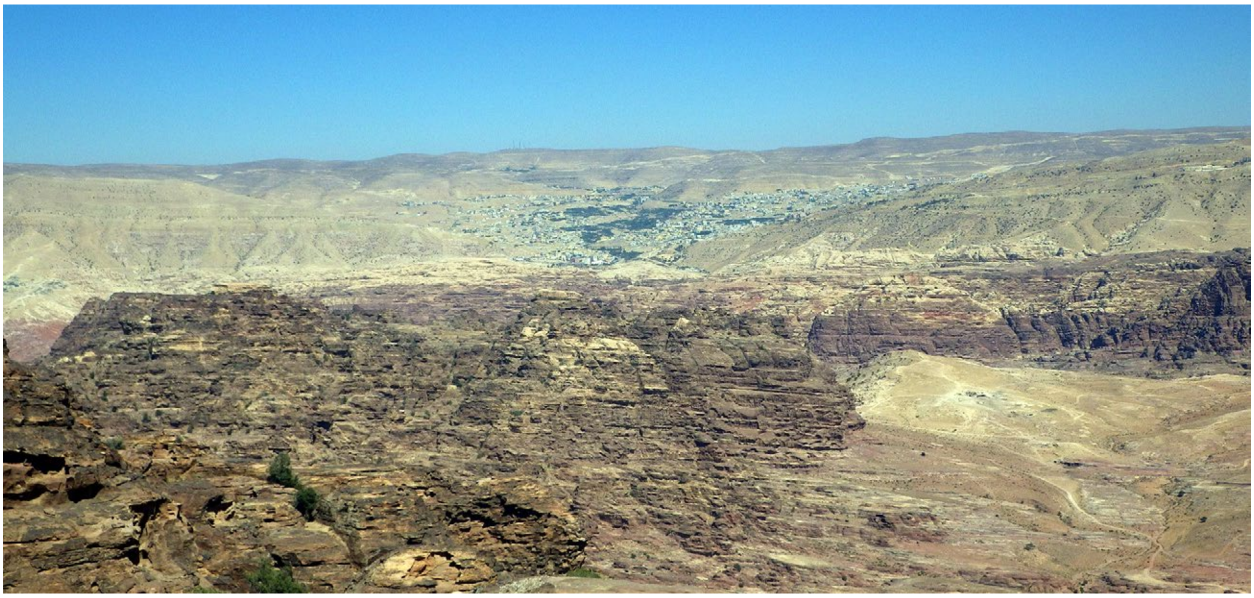

Figure 3. Wadi Musa with its green, spring-fed valley and modern settlement (centre background), at the feet of the Jabal-as-Shara mountains, seen from Jabal Haroun (photo. B. Lucke, September 2016).

found that the soils behind terrace walls in both study areas were derived more or less completely from aeolian sediments. This permitted various conclusions on sources and dynamics of Holocene dust deposition, which were published extensively (Lucke *et al.* 2019b, 2019c; Lucke and Bäumler 2021), but not yet results with regard to the potential use of these terraces for runoff-irrigated cultivation. This contribution will present a short summary of the so far available evidence from the Petra region, which will be substantiated with more detail in forthcoming publications.

Ancient agricultural terrace remains around ancient Petra, southern Jordan?

The ancient city of Petra is hidden in a valley of deeply dissected sandstone cliffs which provide spectacular scenery and obscure access to the city. However, the arid climate poses severe limitations to cultivation, the location in the valley is prone to flash floods, and soils are poor. So far it is unknown how food supply of the ancient city was organized. Avni (2022) claims that the Jabal as-Shara, about 25km[1] to the north-east of the city, could have provided sufficient staple crops as approximately 300mm annual precipitation fall in these mountains. However, it is unclear on which estimates or data this idea is based. The agricultural area of the Jabal as-Shara mountains is limited while land transport through the rugged terrain is difficult. There is no known evidence for large-scale production in that area during antiquity, but it should be mentioned that remains of large irrigation systems (utilizing both diverted runoff and groundwater tapped by underground *qanat* tunnels) were found to the east of Petra in the surroundings of the city of Udruh. This city started to expand when Petra began to shrink (Kouki 2012; al-Karaimeh 2019).

After the Roman annexation, Petra carried the title *Metropolis* and had probably around c. 20,000 inhabitants at its heyday. In this context, ancient *Metropoleis* were always connected to the sea, apparently due to reasons of food supply (Garnsey 1983; see Lucke 2008 for a summary of the logistics of food supply during antiquity), and Petra is a notable exception. Supplying such a huge city with food is a much greater task than feeding the c. 1000 people at Nessana in the Negev desert, where ancient written evidence from the Nessana scrolls indicates that around 1000 persons could have been supported by ancient harvests from Nessana's hinterland (Mayerson 1962). Excavations of private dwellings demonstrated that Petra's staple foods were mainly produced locally (Bouchaud *et al.* 2017), but the sources and quantities of food supply for her urban population were rarely discussed. Some authors assume that Nabatean agricultural installations in small valley oases, such as Wadi Musa with its spring in the valley leading towards Petra (**Figure 3**), may have provided subsistence (Al-Muheisen 1992; Al-Salameen 2004; Kouki 2012; Erickson-Gini 2012). However, well-calculated estimates are not available.

Therefore, it should not be a surprise if the vicinity of Petra was intensely farmed, as this may have been her

[1] Corrected estimate of distance as only the area around Shawbak and further north is suited for rain-fed agriculture. Avni (2022) assumes that 5-10km to the east of Petra, large, well-watered areas are available for agriculture, which is not the case.

Figure 4. Terrace remains near Petra, opportunistically ploughed and used for growing cereals by Bedouin. Person in the background gives scale. Note the germinated cereals, which did not receive good rainfall in that season (photo. B. Lucke. February 2020).

subsistence backbone permitting trade and settlement (Frösén 2004). It was one of the main purposes of the Finnish Jabal Haroun Project (FJHP) to identify such ancient agricultural areas, and it focused on Jabal Haroun as this area could be identified as farmland mentioned in the Petra papyri. These papyri describe legal issues, including land property rights of the 6th century CE (all dates are CE unless otherwise specified), and could be retrieved by excavations of the Petra church (Frösén 2000). Subsequently, the FJHP survey identified a multitude of areas that could have been subject to cultivation with runoff-irrigated terraces (Lavento *et al.* 2013), but it is still unclear how this system operated in detail, and whether it could have provided sufficient produce to feed the ancient city of Petra. In this context, the description of agricultural fields in the papyri as small-sized plots of 0.5 – 5 iugera (c. 0.13 – 1.3ha, or c. 1300 – 13,000m^2), sometimes located above or below from each other, matches the terraces. Many of these terrace remains are today still subject to grazing and petty, opportunistic cereal cultivation by the Bedouin living in the area (Kouki 2013), but the current use does not appear suitable for intensive agricultural production (**Figure 4**).

As it seems questionable from an agricultural point of view whether terracing of steep, barren dryland slopes is worth the effort, Al-Qudah *et al.* (2016), Harmarneh *et al.* (2022), and Abu-Jaber el al. (2022) proposed that terracing of small first-order valleys around Petra was carried out by ancient Nabateans *on catchment scale* in order to minimize runoff before a flood could develop. The terrace remains include many small walls, starting from the very top of the catchments (**Figure 5**): such a large-scale terracing effort of the hinterland could indeed have provided effective flood protection of the ancient *Metropolis* as it would slow down and manage runoff before a flood could develop (Abdelal *et al.* 2021). However, the opposite development appears possible, too: that cultivation was practiced first, based on small runoff-collecting terraces in the upper catchments, and that then, as a by-product of these agricultural activities on landscape scale, flash floods in the lower valleys of Petra were greatly reduced, which permitted construction of the city.

It should be mentioned that the valley of Petra was covered by a huge lake during the Late Pleistocene and Early Holocene. Lake sediments covering the sandstone rocks into which the city of Petra were carved may only have been eroded during the Late Holocene (Abu Jaber *et al.* 2020). This might explain why archaeological material from the Iron Age was found mainly in the upper catchments of valleys at the site (Abu-Jaber *et al.* 2022) and could indicate that terrace construction around Petra might have been connected with another

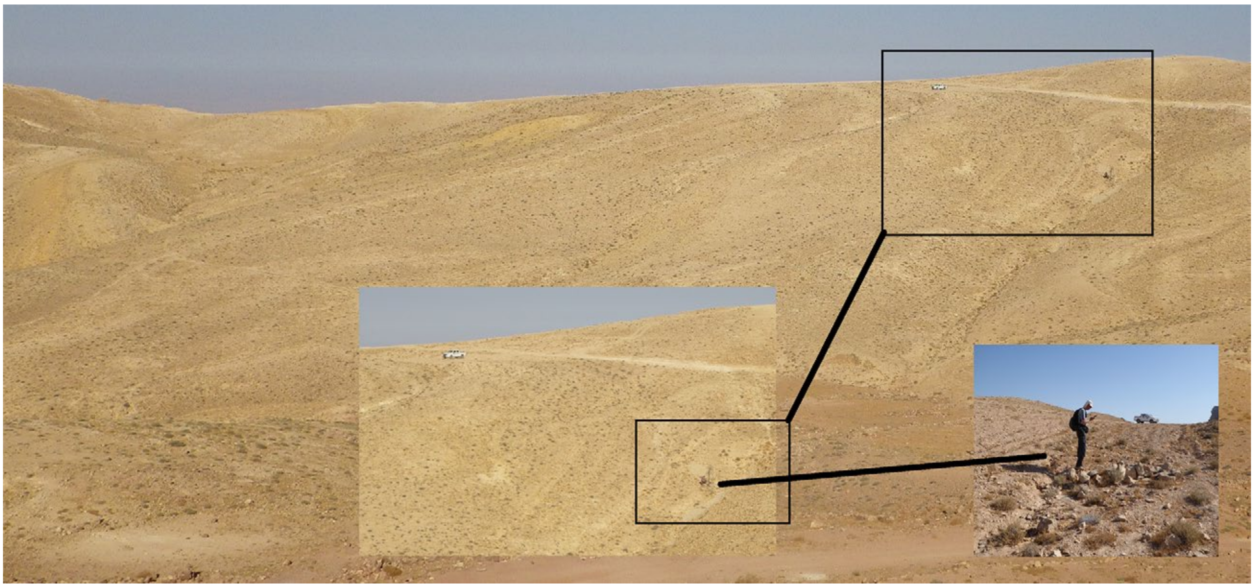

Figure 5. Dolomitic limestone ridge at Jabal Haroun near Petra. Car gives scale. What appears at first sight as a barren, dry mountain reveals numerous remains of small terraces on the ground, crossing initial first-order valleys and slowing down runoff from its very beginning (photo. B. Lucke, September 2016).

'geomorphological window of opportunity' (analogous to Avni *et al.* 2006 for the Negev). However, the past extension and removal of lake sediments in the area were not yet fully reconstructed, and this will remain challenging as only deposition, and not removal, can be well dated.

What is known is that written sources from the 4th century BCE state that the Nabateans were nomadic herders and traders, whereas sedentary rural settlements appear in the surroundings of Petra during the 2nd-1st century BCE (Kouki 2012). Available ages of terrace sediments point to accumulation mainly from the 1st until the 13th century (Beckers *et al.* 2013), i.e. during the Nabatean till Middle Islamic period, but OSL-ages of rock surface burial suggest that at least some terraces were apparently built already in c. 1300 BCE (al-Khasawneh *et al.* 2022).

Materials and methods

The investigation sites

Sampling focused on terrace remains on the Jabal Haroun mountain, south-west of ancient Petra, where the Finnish Jabal Haroun Project (FJHP) had identified a large runoff cultivation system. The western slope of Jabal Haroun hosts numerous terraces below a high sandstone scarp, bordered by a dolomitic Turonian limestone ridge of the Wadi as-Sir formation, which reflects geological horst structures connected with the Dead Sea fault. The Wadi As-Saddat emerges between the sandstone and limestone slope, and hosts remains of sturdy barrages. One such barrage was studied with a profile on the sandstone slope (Terrace on sandstone Jh site 33, N 30.31404, E 35.39839; in the centre of sector C of site 33 of the FJHP), and one smaller terrace with a profile on the dolomitic limestone (Terrace on limestone Jh site 60, N 30.31244, E 35.39476; FJHP area K, site 60) (**Figures 6 to 8**).

As well, sediments behind wall remains of a rectangular enclosure on the top of the Jabal Haroun table mountain were sampled. This area is located directly next to the ruins of a Byzantine monastery and might have been used as garden, as it could have been irrigated with water from large cisterns in the monastery. We excavated a profile near the centre of the enclosure (N 30.31665, E 35.40518; FJHP site 2) (**Figures 6 to 8**).

Methods

A broad range of soil and sedimentological analyses were conducted, including soil colour, pH in water, electrical conductivity, contents of $CaCO_3$, total organic carbon (TOC), and nitrogen. Grain sizes were determined by Sedigraph and laser diffraction (the latter method had to be used for small dust samples) without removal of $CaCO_3$. Major elements and selected trace elements were determined by energy-dispersive X-ray fluorescence (XRF), whereas effective cation exchange capacity (CEC) was determined according to Trüby and Aldinger (1989). Plant-available phosphorus was extracted according to Olsen *et al.* (1954), and magnetic susceptibilities were examined with an Agico Kappabridge device.

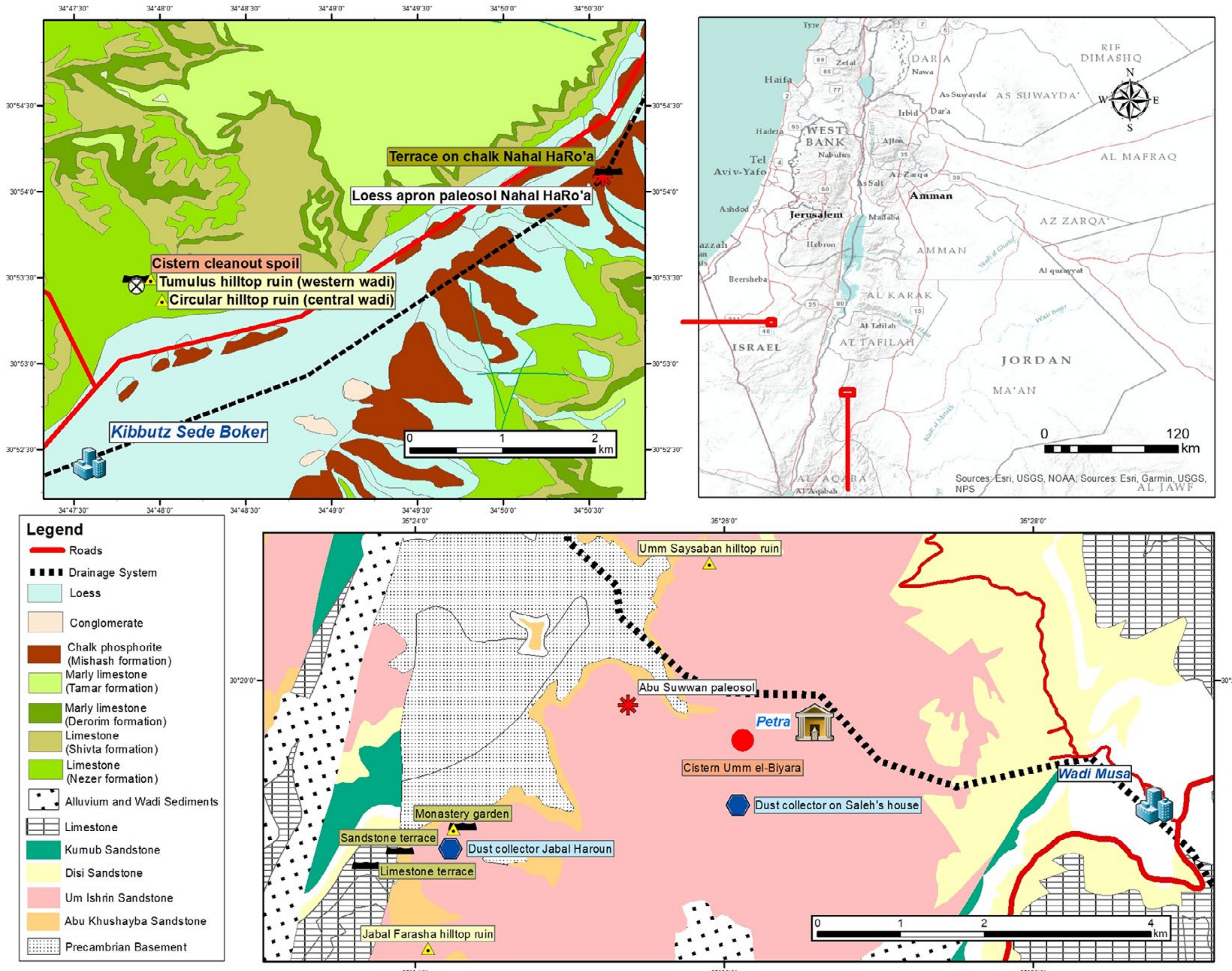

Figure 6. Map of the study areas, showing major geological units (after Barjous 2003, and Avni and Weiler 2013) and the project sampling sites: dotted triangles mark hilltop ruins, walls show terraces, circles indicate cisterns, asterisks mark reference sites, and hexagons current dust traps. This contribution focuses on results from the sandstone terrace, limestone terrace, and monastery garden on the Petra map (sources and copyright of the topographical and terrain basemaps: Esri, USGS, NOAA, Garmin, NPS; used according to Esri Master License Agreement. From Lucke and Bäumler, 2021, p. 3, fig. 1, creative commons license CC-BY).

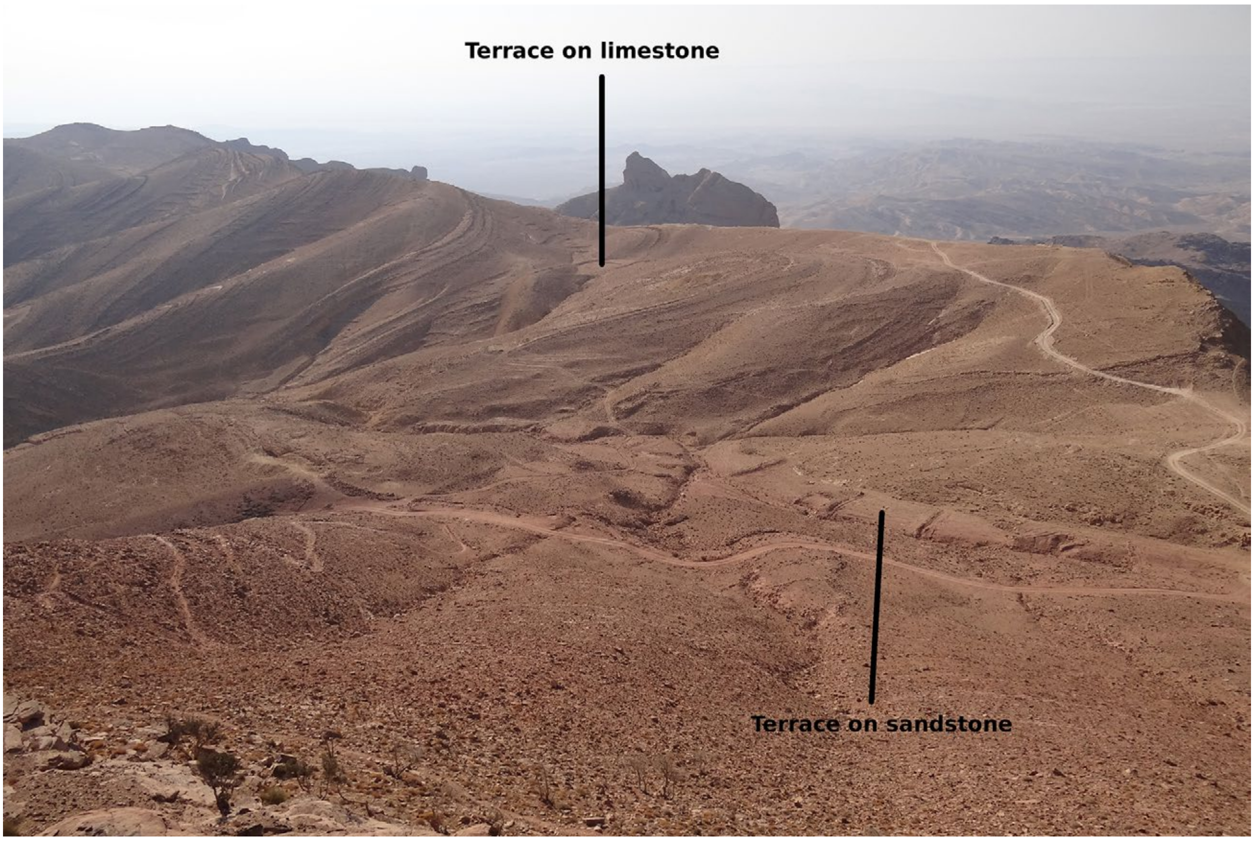

Figure 7. View on the investigated terraces on sandstone and limestone on Jabal Haroun. The valley Wadi As-Saddat emerges between the terraces, separating a ridge of dolomitic limestone from sandstone. The ridge above the terrace on limestone is seen in figure 5 (November 2017, photo. B. Lucke, from Lucke *et al.* (2019d), fig. 1, p. 2, creative commons license CC-BY).

Stanols as faeces biomarkers were extracted according to Birk *et al.* (2012). We calculated the following ratios from the measured concentrations of stanols that indicate faeces remains from omnivores and herbivores (see also Lucke *et al.* 2019d):

- Stanols ratio 1 = (5β-cholestan-3β-ol + 5β-cholestan-3α-ol)/(5α-cholestan-3β-ol+5β-cholestan-3β-ol + 5β-cholestan-3α-ol)
- Stanols ratio 2 = (5β-stigmastan-3β-ol + 5β-stigmastan-3α-ol)/(5α-stigmastan-3β-ol + 5β-stigmastan-3β-ol + 5β-stigmastan-3α-ol)
- Stanols ratio 3 = (5β-cholestan-3β-ol + 5β-cholestan-3α-ol)/(5β-stigmastan-3β-ol + 5β-stigmastan-3α-ol)

Elevated values of stanols ratio 1 indicate the presence of faeces from omnivores, and stanols ratios 2 mark the presence of faeces from herbivores. Stanols ratio 3 represents the relative contribution of omnivore faeces against herbivores, with higher values pointing to a stronger contribution of omnivore faeces (Prost *et al.* 2017).

In order to obtain ages of sedimentation and land use, Optical Stimulated Luminescence (OSL) was applied for sediment samples, typological dating to material culture found in and around the profiles, and radiocarbon dating to charcoal and bones in the sediments.

For a detailed description of methods, see Lucke *et al.* (2019c, 2019d). In addition, phytoliths were extracted following a protocol adapted from Rosen (2005), and pollen could be retrieved following the sieving and swirling method of Hunt (1985), but these results still have to be presented in forthcoming publications.

Results

Sediment depths and general soil properties

Field and laboratory results are summarized in **Figure 9 and Tables 1 and 2**. The terrace on sandstone (Jh site 33) had been ploughed by local Bedouins not long before sampling. The surface was covered by numerous stones, while the soil was dominated by sand, of friable structure, and poor in $CaCO_3$ until a depth of 70cm (**Figure 9**). Occasionally, sandstones were present,

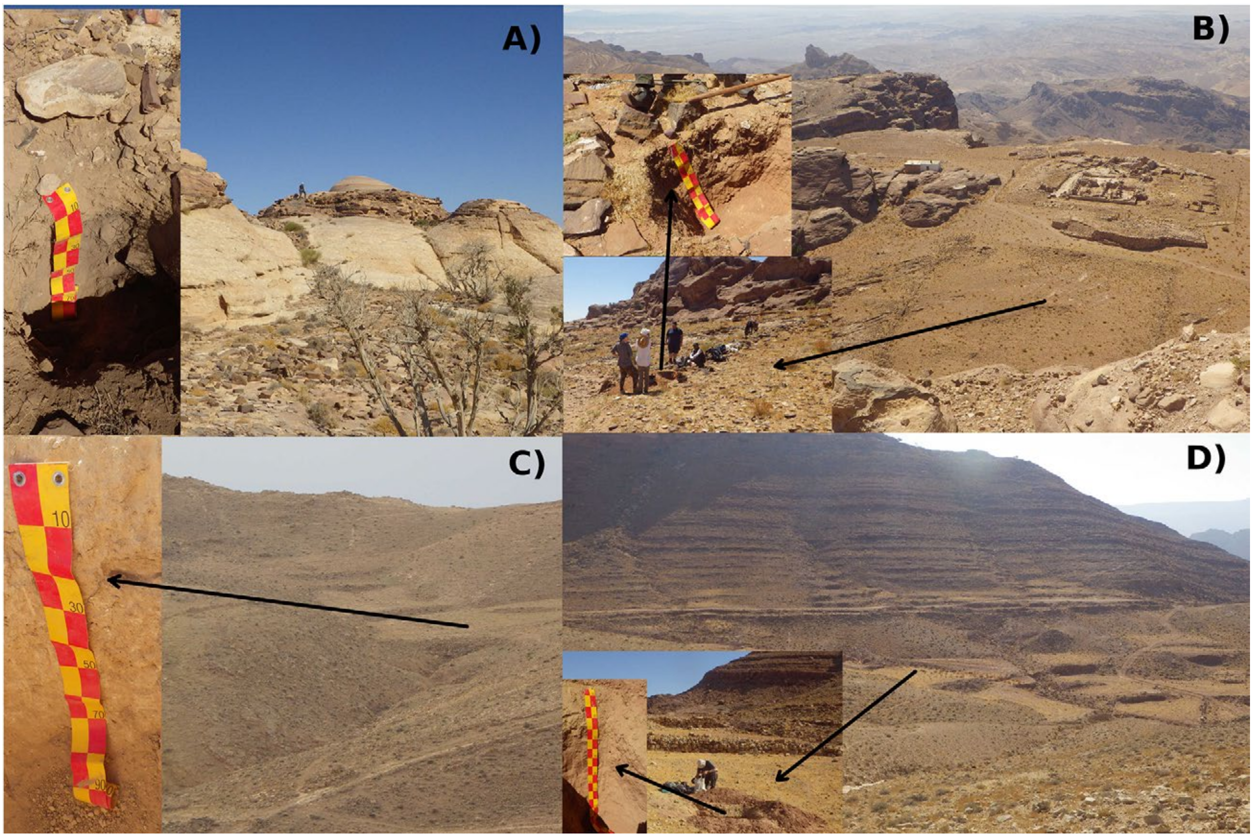

Figure 8. Sampled profiles: A) paleosol preserved below the unexcavated pre-pottery Neolithic site of Abu Suwwan (reference soil; the archaeological site is the stone scatter in front of the picture. Person in the background gives scale). B) Profile in the enclosure/probable monastery garden on Jabal Haroun, seen from the shrine of prophet Aaron. Note the rectangular wall remains below the ruin of the monastery, which apparently surrounded the garden. The stone pile between the monastery ruin and the rectangular enclosure is excavation debris. C) Profile in the runoff-collecting terrace on dolomitic limestone. D) Profile in the runoff-collecting terrace on sandstone. Note the parallel lines on the steep sandstone slope in the background, which partly consist of geological layers, and partly of remains of ancient terraces. The tape measure is in cm (from Lucke *et al.* 2019c, figure A2, creative commons license CC-BY).

ranging from small stones up to fist-size. From 70-140cm depth, soil structure changed and became compact and platy, very poor of stones, rich in $CaCO_3$, and dominated by silt (see **Tables 1 and 2**). At the bottom at around 150cm depth, angular sandstone debris appeared which apparently represents a former rock-covered slope, as currently present on other sandstone slopes in the close vicinity that do not carry terraces. Sediments had reached the top of the terrace wall, i.e. the construction had completely filled with sediment. No artifacts were observed in the profile of the terrace on sandstone, but a few Nabatean sherds were found on the surface (Lucke *et al.* 2019c). The soil of the sandstone terrace was classified as Protic Calcaric Arenosol (Colluvic) over Protic Calcaric Regosol (Colluvic) according to WRB (2015).

The soil profile in the terrace on dolomitic limestone (Jh site 60) was very homogeneous and revealed a compact, calcareous, silt-dominated substrate of 60cm depth. Only the upper 10cm were of friable structure, probably due to recent ploughing by Bedouin. Similar to the terrace on sandstone, angular limestone debris was met in the bottom of the profile, probably representing a former rock-covered slope as present where terraces are absent. Limestones were occasionally encountered in the profile, ranging from small stones up to fist-size, which suggest a gravity-driven contribution of debris from the surrounding, weathered limestone rock. Sediments had reached the top of the terrace wall, i.e. the construction had completely filled with sediment. No artifacts were observed in the profile of the terrace on limestone, but a few Nabatean sherds were found on the surface (Lucke *et al.* 2019c). The soil was classified as Protic Calcaric Regosol (Colluvic) according to WRB (2015).

The profile in the rectangular enclosure next to the ruins of the monastery on top of the mountain was found to be 70 cm deep. It was sand-dominated, poor in

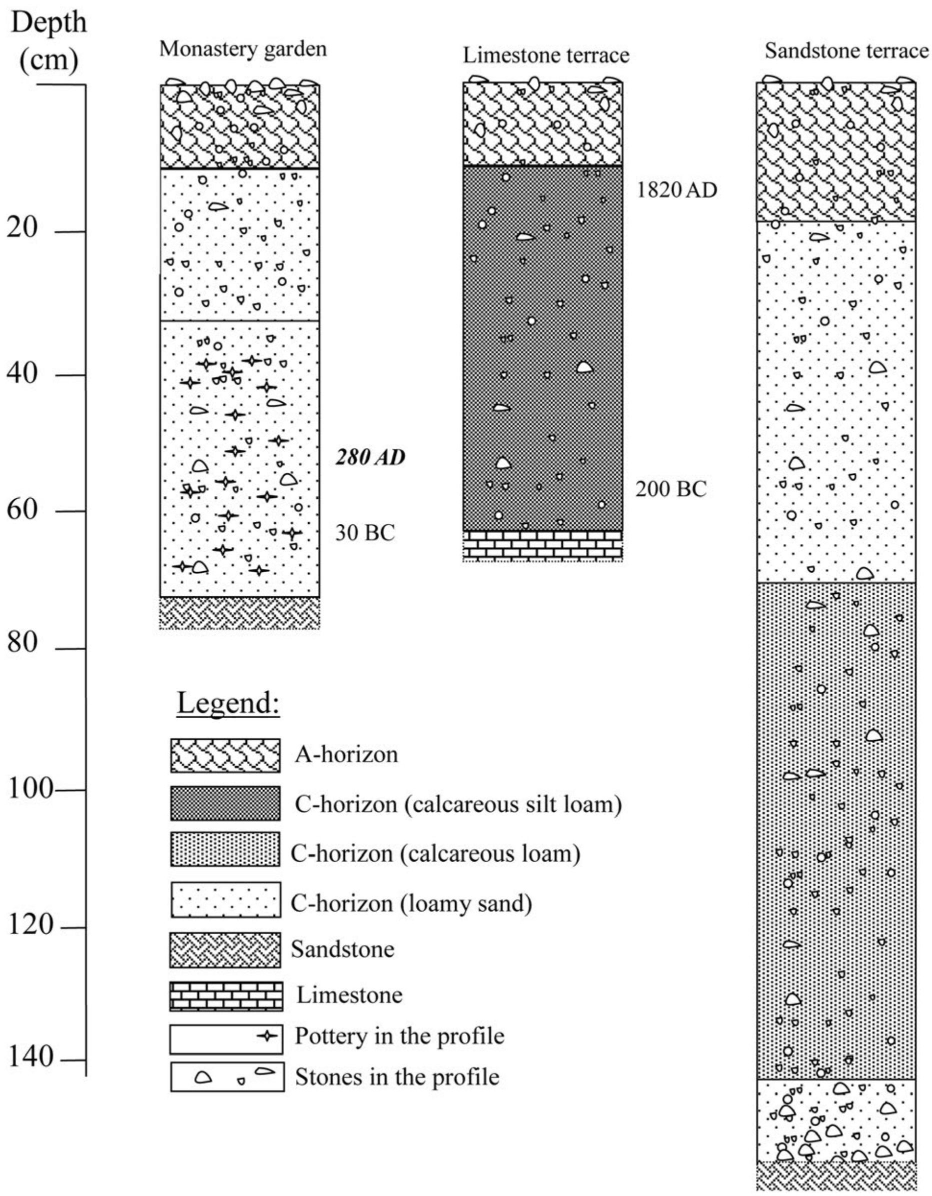

Figure 9. Schematic profile drawings showing available ages (OSL-ages in normal letters, and ^{14}C-ages in bold and italics), as well as horizons and substrates (figure modified from Lucke *et al.* 2019c, figure 3, p. 9, creative commons license CC BY).

$CaCO_3$, and contained few small stones. While the upper 35cm showed rose colour, this changed to greyish-red at 35-60cm depth. In this depth, pieces of charcoal, bones, and pottery were found, which was interpreted to result from the deposition of household garbage. At the very bottom, numerous weathered, flat sandstones appeared as are characteristic for the bare surface of the table mountain. The soil was classified as Protic Arenosol (Alcalic, Ochric) according to WRB (2015).

Terrace and sediment ages

Available ages from the profiles indicate that the structures were originally constructed during the Nabatean period (**Figure 8**; for detailed results and a discussion of age interpretation including error ranges, see Lucke *et al.* 2019c). There is a good agreement of sedimentation ages (determined by OSL) and those of associated material such as artifacts and charcoal (determined by typology and ^{14}C). The OSL-sample obtained from the bottom of the terrace on limestone in 60cm depth yielded a sedimentation age of 340 BC-50 CE (error range), which covers a major part of the time of the establishment of the Nabateans in the area and does thus not permit deciding whether construction of the terrace pre-dates the erection of the monumental city in the valley or not. Near the surface in 20cm depth, an OSL sedimentation age of 1800-1850 CE was

Table 1. Selected results of soil analyses: pH, electrical conductivity (EC), cation exchange capacity (CEC), total organic carbon (TOC), nitrogen (N), and the ration of total carbon to nitrogen (C/N). As well, plant-available phosphorus (P) and total phosphorus and their ration are presented. Stanols ratios were calculated as described in methods. Elevated results of ratio 1 indicate the presence of faeces from omnivores, and stanols ratio 2 marks the presence of faeces from herbivores. Stanols ratio 3 represents the relative contribution of omnivore faeces against herbivores, with higher values pointing to a stronger contribution of omnivore faeces (n.a. = not analysed).

Sample No.	pH (H_2O)	EC (µS/cm)	$CaCO_3$ %	CEC cmol/kg	TOC %	N %	C/N	Plant-av. P (mg/kg)	total P (mg/kg)	% plant-av. P of total P	Stanols ratio 1	Stanols ratio 2	Stanols ratio 3
Monastery garden													
Jh Site 2 10cm	8.5	224	4	12.5	0.27	0.06	4	4.6	912	0.50	n.a.	n.a.	n.a.
Jh Site 2 20cm	8.6	187	3	12.9	0.22	0.05	4	5.2	791	0.66	n.a.	n.a.	n.a.
Jh Site 2 30cm	8.8	177	3	13.8	0.23	0.05	5	4.9	920	0.53	n.a.	n.a.	n.a.
Jh Site 2 40cm	8.9	173	3	15.7	0.24	0.06	4	4.2	722	0.58	n.a.	n.a.	n.a.
Jh Site 2 50cm	8.8	208	3	15.9	0.22	0.04	5	5.9	741	0.79	n.a.	n.a.	n.a.
Jh Site 2 60cm	8.5	113	3	13.8	0.09	0.02	4	6.3	506	1.24	n.a.	n.a.	n.a.
Jh Site 2 70cm	8.7	200	4	16.2	0.16	0.06	3	4.7	463	1.01	n.a.	n.a.	n.a.
Terrace on sandstone													
Jh site 33 10cm	8.8	239	39	18.3	0.26	0.07	4	15.7	927	1.69	0.65	0.48	0.16
Jh site 33 30cm	8.4	363	11	14.4	0.02	0.05	0.4	0.8	590	0.14	n.a.	n.a.	n.a.
Jh site 33 50cm	8.3	374	7	14.3	0.01	0.04	0.2	0.9	431	0.22	0.56	0.40	0.75
Jh site 33 75cm	8.7	573	15	23.7	0.04	0.06	1	1.4	789	0.17	0.60	0.23	0.85
Jh site 33 100cm	8.8	688	23	27.8	0.08	0.06	1	1.9	991	0.19	n.a.	n.a.	n.a.
Jh site 33 130cm	8.7	688	28	24.6	0.13	0.07	2	2.5	853	0.29	0.43	0.31	0.70
Jh site 33 150cm	8.9	599	24	22.1	0.10	0.05	2	6.3	657	0.96	0.50	0.45	0.64
Terrace on limestone													
Jh limestone 0cm	8.8	228	55	20.5	0.70	0.09	8	20.8	1236	1.68	0.61	0.34	0.31
Jh limestone 20cm	8.7	153	55	21.5	0.62	0.07	9	3.9	945	0.42	0.71	0.19	0.55
Jh limestone 40cm	8.7	207	58	18.4	0.56	0.07	8	2.1	915	0.23	0.62	0.26	0.61
Jh limestone 60cm	8.8	518	55	21.9	0.49	0.06	8	1.8	833	0.22	0.47	0.36	0.28

Table 2. Grain size distributions of the terrace soils, determined by Sedigraph measurements without removal of $CaCO_3$. Sub-fractions are given in italics and are automatically rounded so that sums not always match total sand, silt and clay fractions.

Sample No.	Skeleton > 2 mm (%)	Sand %	Silt %	Clay %	Coarse sand %	Medium Sand %	Fine sand %	Coarse silt %	Medium silt %	Fine silt %	Coarse clay %	Medium clay %	Fine clay %
Monastery garden													
Jh Site 2 10cm	2	84	7	9	*2*	*63*	*19*	*3*	*2*	*2*	*2*	*3*	*4*
Jh Site 2 20cm	5	86	5	9	*2*	*63*	*21*	*2*	*1*	*2*	*2*	*3*	*4*
Jh Site 2 30cm	12	80	7	13	*2*	*54*	*24*	*3*	*2*	*2*	*3*	*5*	*5*
Jh Site 2 40cm	13	74	9	17	*0*	*50*	*25*	*3*	*2*	*3*	*4*	*6*	*7*
Jh Site 2 50cm	4	80	7	13	*1*	*54*	*25*	*2*	*2*	*2*	*4*	*5*	*5*
Jh Site 2 60cm	9	83	5	12	*2*	*60*	*22*	*1*	*1*	*2*	*3*	*4*	*5*
Jh Site 2 70cm	22	74	9	17	*2*	*52*	*20*	*5*	*2*	*2*	*4*	*5*	*8*
Terrace on sandstone													
Jh site 33 10cm	26	66	27	7	*11*	*20*	*35*	*13*	*8*	*7*	*4*	*1*	*1*
Jh site 33 30cm	6	73	15	12	*4*	*25*	*45*	*7*	*4*	*4*	*4*	*3*	*5*
Jh site 33 50cm	3	74	15	11	*3*	*21*	*50*	*7*	*4*	*4*	*4*	*3*	*4*
Jh site 33 75cm	1	32	41	27	*0*	*2*	*30*	*17*	*12*	*11*	*9*	*8*	*11*
Jh site 33 100cm	0	16	45	39	*0*	*3*	*13*	*10*	*16*	*19*	*13*	*6*	*20*
Jh site 33 130cm	3	31	36	33	*2*	*10*	*20*	*7*	*12*	*16*	*14*	*8*	*11*
Jh site 33 150cm	8	59	23	18	*5*	*19*	*35*	*6*	*7*	*10*	*8*	*5*	*5*
Terrace on limestone													
Jh limestone 0cm	20	36	45	19	*6*	*8*	*22*	*19*	*14*	*12*	*11*	*5*	*3*
Jh limestone 20cm	17	32	47	21	*3*	*4*	*25*	*19*	*15*	*13*	*11*	*6*	*4*
Jh limestone 40cm	30	34	41	25	*6*	*7*	*21*	*14*	*14*	*13*	*12*	*8*	*5*
Jh limestone 60cm	18	29	43	28	*4*	*6*	*19*	*17*	*13*	*14*	*12*	*7*	*8*

obtained, but with a huge scatter of signals (Lucke *et al.* 2019c). This could be explained with a mixture of older and recently sedimented grains, which probably took place because the terrace wall had completely filled up. Thus, it could barely store new sediments, but was occasionally ploughed, so that younger grains were mixed with older sediments.

In the rectangular structure at the monastery on the mountain, an OSL sedimentation age of 150 BC-90 CE was obtained near the bottom at 60cm depth, suggesting that the rectangular enclosure had already been there before the monastery was built to cover a pagan sanctuary. A charcoal piece obtained from 50cm depth yielded a ^{14}C-age of 239-327 AD, potentially indicating gardening activities in the area before the city of Petra officially converted to Christianity during the 5th century. Some pottery sherds were observed both on the surface and in stratified context in the profile: while material of Late Roman style was encountered at the bottom in 70cm depth, two Early Byzantine pieces were encountered at a depth of 40cm. A few Late Byzantine and Early Islamic pottery sherds were found at the surface (Lucke *et al.* 2019c).

Land-use related soil properties

While general results of soil analyses have been presented in detail and discussed elsewhere (Lucke et a. 2019b, 2019c; Lucke and Bäumler 2021), some parameters relevant for soil fertility are shown in **Table 1**. PH values of all terrace soils are slightly alkaline and range between 8.3-8.9. Electrical conductivities range between 113-688µS/cm, not suggesting salinity. Contents of calcium carbonate are low in the monastery garden with c. 3%, but reach 7-58% in the terraces, with high contents in particular in the terrace on limestone.

Cation exchange capacities (CEC) range from 12.5-27.8cmol/kg, while base saturation was always 100%. CEC seems connected with grain sizes, with strong positive linear correlation with the clay and silt fractions (not shown here).

Contents of total organic carbon (TOC) are all below 1%. As well, nitrogen contents are very low (close to the detection limit) and seem to include inorganic nitrogen. C/N ratios range between 0.2-9, which is low, indicating that N availability for plants would be good if N was added to the soils.

Plant-available phosphorus in terrace sediments ranges between 1.4-20.8mg/kg, while the monastery garden shows more uniform values of 4.2-6.3mg/kg. The surface samples of the terrace on sandstone and the terrace on limestone fall out with 15.7 and 20.8mg/kg, respectively. Total phosphorus contents range between 463-1236mg/kg and largely follow the distribution of plant-available phosphorus. However, there is no linear correlation, but the fraction of plant-available P in total phosphorus is with 0.5-1.69% higher in those samples where absolute amounts plant-available phosphorus are high. Samples with low absolute amounts of plant-available phosphorus are characterized by lower fractions of plant-available P in total phosphorus, ranging from 0.14-0.42%.

So-far available biomarkers show an increasing share of omnivore excrements in the bottom and central part of the terrace profiles on limestone and sandstone (**Table 1**). Stanols results are given in ratios as this eliminates the potential effect of 'dilution' with mineral sediment. Relatively high values of stanol ratios 1 and 3 suggest the presence of excrements with high share of omnivore faeces, i.e. deposition of human or pig excrements.

Discussion

Sedimentation processes and origin of terrace substrates

The varying depth of the profiles could to some degree be connected with catchment sizes: the terrace on sandstone, which is fed by the largest catchment, revealed the deepest sediment profile (see Lucke *et al.* 2019c for more detailed calculations and considerations of sedimentation rates). The least profound profile, however, was found on the terrace on limestone, although the monastery garden has the smallest catchment (this enclosure has in fact no associated runoff-collecting area, which is the reason to expect irrigation from the adjacent monastery's large cisterns). This brings us to the role of terrace maintenance: it seems likely that profile depth is not only connected with sediment supply, but also with the height of the terrace wall, so that sedimentation rates were greatly reduced when regular maintenance and re-construction of the walls stopped. This is the case in the terraces on sandstone and limestone and supported by strongly scattering OSL-signals in the topmost sample from the terrace on limestone, which indicates a mixture of young with old material (Lucke *et al.* 2019c). In this context, an age scatter is present in the bottom sample of this terrace, too, although not as pronounced as in the top sample: this may hint at the presence of earlier sediment bodies which were incorporated into the terrace. Therefore, the OSL-age of c. 200 BCE for the bottom sample is a minimum age: it does not exclude that earlier structures were present. The age scatter might be taken as indication of a Nabatean-period *re*-construction of terraces which incorporated older sediments into the rebuilt system.

The profile in the monastery garden seems still collecting sediment, as the top of the walls was not yet reached. The similarity of calculated average accretion rates in the monastery garden with current dust collectors (Lucke *et al.* 2019c) indicates that the soil of the monastery garden is a product of direct and apparently rather continuous aeolian deposition without amplification or variation caused by terrace maintenance and runoff management. It should be noted that no disturbances or discordances were noted in any of the studied profiles that could indicate hiatus or major changes of sedimentation regimes. Therefore, it can be concluded that hilltop profiles such as the monastery garden probably continuously stored sediments until the present day, which makes them potential, new environmental archives (Lucke *et al.* 2019b). Sediments in terraces on slopes can, in principle, also serve as environmental archive, but interpretation is more difficult as land management, in particular changes of the runoff regime due to upslope terrace construction and maintenance, played a role for sedimentation processes.

No laminations or thin sediment layers could be observed in the terrace profiles. This contrasts with the Negev, where periods without agricultural use were apparently associated with banded layers in terrace sediments (Lucke *et al.* 2019c). It seems thus possible that the terraces on Jabal Haroun were occasionally ploughed all the time since their construction, at least more frequently than sediments could accumulate up to plough depth, as ploughing would obliterate layering (Bruins *et al.* 2020). This is supported by the present-day ploughing and occasional re-use of terraced areas near Petra by local Bedouin.

The substrate of terrace soils proved to be more or less completely aeolian dust, as has been extensively discussed elsewhere (Lucke *et al.* 2019b, 2019c; Lucke and Bäumler 2021). This includes a significant local contribution from nearby rock exposures, but it is important to note that the deposition of fines (clay, silt, and sand) took place by aeolian processes, and not by runoff-driven erosion of surrounding rocks or soils. This can be concluded from the nearly identical composition of the terraces and hilltop sites, where sediments were clearly deposited from aeolian sources (Lucke *et al.* 2019b). Silt and calcium carbonate were in this context found markers for dust from remote sources, while medium sand, which is dominating the rather coarse substrate of the profile in the monastery garden, proved derived from nearby sandstones. In the case of the monastery garden, sandstone cliffs with many tafoni overlook the place and illustrate the role of wind erosion from proximal rocks (Lucke *et al.* 2019c).

A layer change to more sandy and less calcareous material can be noted in the upper part of the terrace on sandstone, which seems the most significant change of sediment properties. No similar changes can be observed in the other profiles. Unfortunately, no ages are so far available from the terrace on sandstone. Higher sand contents could be interpreted as increasing contribution from weathering sandstones, but it should be noted that changes can mainly be noted in the fine sand fraction (**Table 2**), not medium sand which is the characteristic grain size of the surrounding sandstone rocks. Two explanations seem possible: 1) more sand became available, perhaps due to lack of maintenance of upslope terraces, which led to re-deposition of sandy material. This cannot be excluded, although it is unlikely that substrate composition of upslope terraces would comprise a higher fine sand fraction than the silt-dominated, lower part of the studied terrace. 2) Dust sedimentation changed to higher sand contents, possibly due to higher wind speeds and/or changing sediment fixation processes on the terrace, where a shift from silt and clay towards sand could be interpreted as a drought indicator (Lucke *et al.* 2019b). If true, the increase of sand in the upper part of this terrace might correspond to the major arid episode of the second Little Ice Age (14th-19th century) found by Hunt *et al.* (2007) in nearby Wadi Feinan, but in the light of lacking ages from this profile, this has to be left open for now. In case ages fit, it would have to be discussed why no similar changes towards more sandy grain sizes can be observed in the terrace on limestone: a possible explanation could be that the smaller wall of this terrace had already largely filled up during this time. The monastery garden, in contrast, would not have recorded such changes of dust composition as its substrate is largely derived from the nearby sandstone cliff.

Soil properties related to land use

Soil properties show no indications that could be detrimental to cultivation but appear typical for an arid environment. There is no in-situ pedogenesis with regard to chemical weathering (Lucke *et al.* 2019c). PH values are all slightly alkaline, which is characteristic for an arid environment, and agrees with base saturations of 100%. CEC values seem to mirror grain sizes as exchange capacities will be dominated by clay minerals. This is connected with minimal contents of organic matter, again typical for an arid environment, which leads to minimal amounts of nitrogen. It means that manuring with organic material could have very positive effects on plant growth if sufficient water is available. EC values do not indicate salinity, but slightly elevated values in the terraces as compared to the probably cistern-irrigated monastery garden might be interpreted as indication for temporary standing water. The latter could have been present after runoff events, as puddles of standing water have been reported for ancient terrace remains in the Negev during several winter weeks after current runoff events (Bruins *et al.* 2019; Bruins 2022). Such episodes could explain why phytoliths and pollen retrieved from terrace sediments near Petra by Abu-Jaber *et al.* (2022) point to periodical standing water bodies that were associated with sediment deposition behind terrace walls.

Soil phosphorus contents

Phosphorus is a key nutrient that is largely immobile and builds up if not consumed by crops. It will accumulate as long as the P sorption capacity is not exceeded, which is high in Ca-rich soils as phosphorus is absorbed to calcium carbonate (Boischot *et al.*, 1950; Hemwall, 1957). In contrast to other nutrients, phosphorus contents may therefore be used to reconstruct intensities of past manuring. However, the greatest part of phosphorus is usually present in form of phosphates with low solubility, which is not available to plants. Sedimentary rocks such as present near Petra can contain strongly varying amounts of such phosphates. Therefore, the content of plant-available phosphorus (according to Olsen *et al.* 1954) could be a better indicator of additions due to manuring if phosphorus application exceeded P offtake by crops (Hooda *et al.*, 2001).

Strongly elevated contents of plant-available phosphorus in the topsoils indicate that the terraces continued to be used when walls were no longer built higher because interviews with local Bedouins suggest that neither fertilizer nor modern garbage were ever added to the terraces. Therefore, organic matter from stubble, dung from grazing, and possibly also organic manure continued to accumulate, whereas sedimentation of mineral soil diminished, which explains high concentrations. The high levels of plant-available phosphorous in the terrace topsoils may also be connected with reduced P offtake by plants, e.g. due to more extensive and/or less successful crop cultivation during continuous supply of dung or manure.

With the exception of the topsoils and the lowermost sample of the terrace on sandstone, contents of plant-available phosphorus in the runoff-irrigated terraces are not significantly higher than in natural soils, and the lowest contents with less than 1mg/kg are present in the sand-enriched layers in the upper part on the terrace on sandstone. This could support the interpretation of elevated sand contents as an aridity signal and thus diminished land use, because erosion and re-deposition of substrate from poorly maintained upslope terraces should only reduce phosphorus contents if those upslope terraces had not been used agriculturally. The high contents of plant-available P in the bottom of the sandstone terrace could be interpreted as indication of pre-existing, manured sediments which were incorporated into a re-designed terrace.

Assuming that contents of c. 2mg/kg or less of plant-available phosphorus represent the natural base-level, it can be discerned that contents of the monastery garden profile are quite homogeneously elevated by a factor of 2-3. This agrees with the apparent continuous deposition of aeolian sediments and suggests that organic matter rich in phosphorus was added throughout the formation of the profile. It further supports the interpretation that the pottery, bones, and charred materials represent the remains of waste associated with manuring, as the highest contents of c. 6mg/kg plant-available phosphorus are reached in the layers associated with these garbage remains. These amounts match the critical levels for wheat production of 5 – 7mg/kg plant-available P found by Ryan *et al.* (2008) for semi-arid soils in Syria. This lets it seem possible that ancient farmers consciously applied a manuring strategy that supplied optimal amounts of organic materials. Furthermore, it seems likely that the runoff terraces were used more extensively than the monastery garden, but some additions of manure seem possible there, too, in particular in the bottom sample of the sandstone terrace.

An alternative explanation for strongly elevated contents of plant-available phosphate in this sample could be the presence of some kind of water reservoir. This would agree with the discovery of a nearby spillway by the Finnish Jabal Haroun Project (Lavento *et al.* 2013) and the massive size of the excavated walls. The presence of such a reservoir would, however, not be consistent with simple flood management, but indicate the presence of a more sophisticated irrigation system, at least for some time during the Early Nabatean period.

With regard to total phosphorus, Lucke and Bäumler (2007) and Lucke *et al.* (2019c) found that Pt-contents of the rocks and natural soils in the area mostly range between 200-500mg/kg. Some rocks, however, can reach up to 1300mg/kg. No clear connection between the contents of plant-available and total phosphorus can be observed, and levels of total phosphorus seem therefore not suited for assessments of past manuring. The high and strongly varying contents of total phosphorus can be explained by varying contributions of geogenic phosphorus from the sedimentary rocks.

Faeces biomarkers

Although analyses of faeces biomarkers were not yet completed, some first interpretations can be drawn from the available stanols ratios. Faeces of herbivores dominate at the surface and in the lower part of the profiles, while a higher presence of omnivore excrements can be stated for the central parts and bottom of the terrace profiles (**Table 1**). This points to deposition of manure from human and pig excrements during antiquity. In this context, ancient papyri uncovered in the Petra church suggest systematic collection, treatment, and application of (human?) excrements (Kaimio 2011), and the breeding of pigs at Petra is attested archaeologically (Bouchaud *et al.* 2017). While herbivore faeces could be derived from grazing and extensive use of the terraces, possibly mainly for runoff control, the presence of omnivore faeces suggests planned manuring.

However, it is likely that herbivore excrements were collected and applied as dung, too, which could explain why there is no connection of omnivore faeces biomarkers with contents of plant-available phosphorus. In this context, it should be mentioned that an ancient double re-use of excrements first as combustible, and then of the ashes as dung, could well be possible (Tehunen 2016). This could mean that charred materials in terrace sediments as reported by Abu-Jaber *et al.* (2022) do not necessarily indicate a clearing of woody vegetation by fire but might have resulted from the application of burnt dung.

Runoff-irrigated terraces in drylands as examples of sustainable land use: the past as perspective for the future

There is no evidence of man-made soil erosion, over-irrigation, or land degradation in the studied area, but on the contrary, the terrace soils near Petra show how ancient land use created agricultural land on formerly debris-covered rocks. This happened outside any 'geomorphologic window of opportunity', as there is no evidence suggesting that Jabal Haroun hosted any significant soil cover during the Nabatean period. In this context, it should be mentioned that not only rocky slopes, but also dryland slopes covered by loess (without vegetation) can create very significant runoff (Bruins and Ore 2009). This is due to surface crusts (biological and physical) which form on the soils and are impermeable to rains when soils are dry (see Lucke 2023b and Lucke *et al.* 2019b, 2019c for an extensive discussion of the potentially very important role of such crusts for soil-forming processes in drylands). Therefore, the idea that runoff-irrigated terrace farming would be bound to specific geomorphic conditions can be discarded: the key issue is occasional rainstorms which generate sufficient runoff for floods.

Although paleosols were preserved below Early Holocene ruins in the Petra region (Lucke *et al.* 2019b, 2019c; see figure 8a), there is no reason to assume that slopes were less rocky and barren than today when the investigated terraces were constructed. Their use over centuries, however, created fertile soils from dust that partly still permit opportunistic cultivation. The main difference to the paleosols is that it was probably higher vegetation cover during the Early Holocene that fixed dust to form the paleosols, whereas crusts and man-made structures were key for dust fixation during the drier Late Holocene (Lucke *et al.* 2019b, 2019c). In this context, it is not a lack of dust supply in arid regions that would prevent the formation of soils derived from aeolian sediments, but missing dust fixation. Dust will be re-mobilized unless held in place by vegetation, crusts, or structures such as runoff-irrigated terraces (Lucke and Bäumler 2021; Lucke 2023b).

Key to productive harvests on runoff-irrigated terraces seems the functioning of the water management system, i.e. the terraces have to be maintained and managed at catchment scale. Otherwise, runoff will concentrate and incise again, damage downstream terraces, and the water will mostly be lost (al-Qudah *et al.* 2016; Abdelal *et al.* 2021). Therefore, current Bedouin yields are not representative for the full potential of the system, but it would need high work input and a well-organized management on catchment scale to restore the runoff-irrigation system to its former status. Experiments from the Negev have shown that such a management might not only make it possible to create oases in an otherwise waterless desert (Evenari *et al.* 1982), but experiments with charcoal, ash, and dung indicate that adding household garbage as fertilizer could significantly improve yields (van Asperen *et al.* 2014; van Bommel *et al.* 2021).

In summary, Petra was in ancient times not located in a desert but apparently surrounded by a man-made oasis. So far available sediment ages suggest that the runoff irrigation system was never completely abandoned, but reverted to a simple, opportunistic use, probably at some time during the Middle Islamic (Medieval) period. Possible reasons for this development could be a weak state that could not any more organise management of the systems at catchment scale, or increasing aridity, in particular the absence of a few strong, runoff-generating rainstorms for several years. In any case, there is any reason to assume that similar systems could nowadays be re-established in desert fringes, creating sustainable oases in areas that might otherwise be desertified due to global warming.

Summary and conclusion

Available sedimentation ages suggest that the studied terrace soils began to aggrade during the 3rd-1st century BCE, which matches the archaeological context of the Early Nabatean period. This time was characterized by population growth and the appearance of rural settlements and farmsteads near Petra and culminated in the carving of the famous city into the sandstone rocks of the valleys. Due to the error range of the OSL dating method, it is not possible to decide whether construction of the terraces pre-dated the building of the city. That means that from the ages alone, it cannot be said whether the terrace system may have been designed primarily in order to protect the urban valley from flash floods. However, scatters of the OSL-signals, as well as elevated contents of plant-available P and omnivore excrement markers in the lowermost samples, can be taken as indication that the now visible terraces are product of a major re-construction of an earlier, probably simpler, system of terraces. This would agree with OSL-ages of rock surface burial below terrace walls in other parts of the Petra region, which indicate that construction of such structures began as early as c. 1300 BCE (Khasawneh *et al.* 2022).

The substrates of terrace soils are derived more or less completely from aeolian dust, i.e. the system harvested not only runoff water, but also aeolian sediments. Thus, fertile soils were created on previously barren rocks. It has to be noted that the terraces are a complex system of walls of very different sizes, which cover slopes at catchment scale. They functioned together and slowed down runoff, thus preventing floods, and stored the runoff water within terrace soils. At the investigated terraces on Jabal Haroun, dust deposition rates were greatly reduced when sediments had accreted to a degree that they reached the top of the terrace walls. Therefore, the system is currently largely dysfunctional, and gullying has begun to remove terraces. However, many are still used opportunistically for growing cereals by Bedouin living in the area, as a large part of the terrace walls is still intact, in particular in the upper part of the catchment.

Faeces biomarkers suggest that omnivore excrements, i.e. from humans or pigs, were deposited in the bottom and central part of the sediment profiles. These are characterised by relatively high silt contents that indicate remote aeolian sources, which might be interpreted as a signal of a relatively moist climate with rain-associated dustfall. The presence of omnivore excrements points to planned application of manure and an agricultural purpose of the system. Excrement biomarkers suggest a change from omnivores to herbivores in the later phase of sedimentation, probably reflecting increased grazing and more extensive use of the area. An associated increase of fine sand in one of the terrace profiles could be interpreted as an aridity signal, or at least as indication of higher wind speeds or more unfavourable rainfall distribution with regard to the floods needed for successful cultivation. This could have been connected with a shift to more arid conditions, possibly in the context of the major arid phase of the second Little Ice Age found at Wadi Feinan (Hunt *et al.* 2007).

However, the studied terraces were apparently never completely abandoned. This can be concluded from the absence of sediment layering, suggesting occasional ploughing, and from strongly elevated contents of plant-available phosphorus in topsoils which support the idea of continuous use, although walls were not built higher any more. Therefore, organic matter from stubble and dung from grazing continued to accumulate while sedimentation of mineral soil diminished.

The terraces were probably not only constructed in order to protect the Nabatean capital from flash floods but may represent what remains of Petra's former agricultural hinterland. Their construction was not connected with a 'geomorphic window of opportunity' but simply took advantage of strong runoff generated by occasional rainstorms in the Petra region, and of the omnipresent dust in the atmosphere of drylands. Therefore, it could be reconstructed today, if sufficient resources would be made available for the substantial necessary hand labour and complex planning required for management of runoff on slopes on catchment scale. But then, it should be possible to again harvest runoff water and aeolian sediments which are presently lost with floods, and to create a man-made oasis on landscape scale, as has surrounded Petra during antiquity. Therefore, the past could show a way how to master the future, if global warming will lead to an expansion of desert ecosystems.

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Chapter 9.
Beyond the Silk Roads Trade: Irrigated Agriculture in the Middle Zeravshan Valley, Samarkand Oasis (Uzbekistan)

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Introduction

The Samarkand oasis is the result of a long socio-environmental interaction that over time transformed a fertile floodplain constrained by a semi-arid environment into one of the most important agricultural basins in Central Asia. The agricultural wealth of the hinterland of this region is usually secondary to Samarkand's reputation as a capital city of great conquerors, or the wealth associated with the rich trade along the ancient Silk Road. Centrally located on the main South-North routes between the Indian Ocean and the Eurasian steppes, and East-West between China and the Mediterranean, Samarkand has always been synonymous with economic, cultural, linguistic, religious, etc. exchanges.

However, since its earliest foundation during the Achaemenid period (6th century BCE) (Grenet 2004; Shishkina 1994) to its most recent history, the city has grown in symbiosis with its territory. The most prominent economic element, shared over the past three millennia, is the skilful integration of irrigated agriculture and pastoralism (Mantellini 2017: 21). Scholars particularly agree on the agricultural peculiarity of Samarkand and Sogdian society in general (de la Vaissière 2005: 17; Marshak and Negmatov 1996: 233). Investigations conducted over the past decades by the Italo-Uzbek Archaeological Project – UIAP 'Samarkand and Its Territory' have shown how this combination contributed to the historical development of the oasis, and how this entailed a massive transformation of the area under research.

This paper focuses specifically on the history of water management in the southern part of the Samarkand region, with particular emphasis on the network of man-made canals that have ensured water supply to the city and surrounding area for centuries. The topic has already been extensively covered and published (Mantellini 2003, 2015, 2018, 2020; Mantellini *et al.* 2009, 2011; Stride *et al.* 2009; Armaroli *et al.* accepted). This contribution will therefore provide a summary of the approach used and the main results obtained.

Research area

The UIAP investigations cover an area of approximately 3500km^2 in the southern sector of the Middle Zeravshan valley (**Figure 1**). This area is a mosaic of ecological variables, ranging from the typical river environment with dense vegetation (*tugai*) to the semi-arid steppe (*chul*) that further West transforms into a desert land up to the Bukhara oasis (Rondelli and Tosi 2006: 459; Shirinov and Tosi 2003). The present-day steppe has been left unexploited for a long time, but recent surveys have revealed the presence of intense occupation in the past, made up of human settlements and a complex network of artificial canals (Galieva 2010, 2017; Galieva and Inevatkina 2005; Mantellini 2015: 6, 2017, 2018) that delimited cultivated fields of different sizes. In the last decade, government programmes aimed at intensive cultivation and the production of green energy through photovoltaic systems are transforming this territory again, often without any form of control and protection of the heritage.

Between these two environmental extremes, there is a rich agricultural plain where individual zones are designated for specific crops: cotton in Pasdargom, vines in Taylak and Urgut, horticulture and fruit trees in the other districts. This subdivision is the consequence of both the legacy of Soviet agricultural policies (Mantellini and Berdimuradov 2019), especially the conversion of many lands to cotton, as well as the adaptation of native species that historically found in this climatic-environmental regime an ideal habitat (Shirinov and Tosi 2003). The southern and eastern borders are defined by the Chakalikalan range (highest point 2585m asl), which is the final offshoot of the Zeravshan mountains on the border with Tajikistan, and the Karatyube range (highest point 2204m asl),

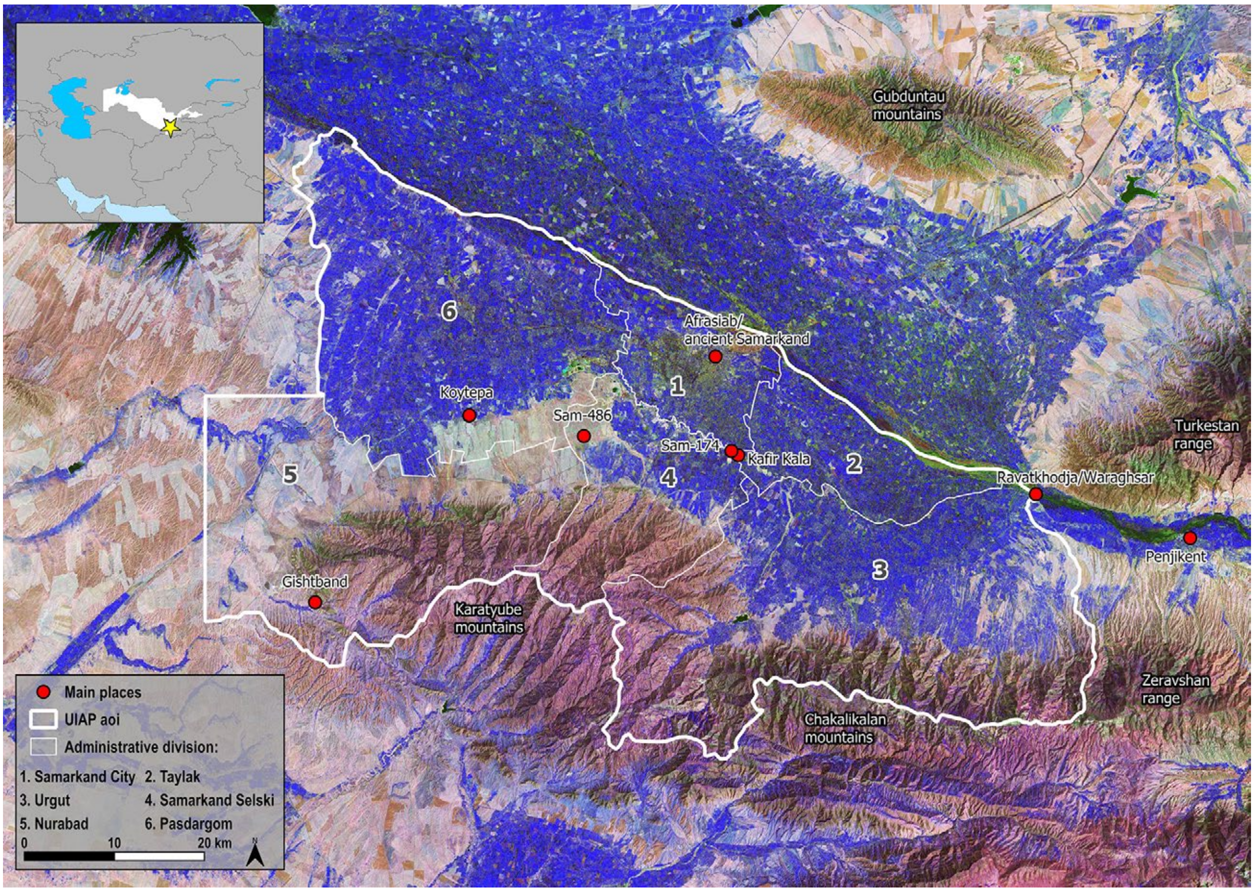

Figure 1. The UIAP research area with the main places and geographical features discussed in this paper, with the waterscape of the Samarkand oasis in the background; Samarkand (yellow star) and Uzbekistan in the box in the top-left corner (basemap: 1987-1991 LANDSAT TM satellite imagery, courtesy USGS; © UIAP 2024).

both dividing the Middle Zeravshan Valley and the Kashkadarya Valley through the Amankutan Pass (1800m asl).

Mapping the settlements

The ecological diversity and the long history of settlement in this territory are reflected in the different land uses and variability of anthropic evidence in the archaeological landscape (Mantellini 2017: 17–18; Mantellini and Berdimuradov in press). If the cultivated floodplain, including Samarkand city and minor urban areas, resulted in the destruction of hundreds of archaeological sites, the present-day steppe gives an excellent picture of the untouched anthropic evidence of the past in this region.

The above-described complexity has made it necessary to adopt a research approach based on the integration of information available (Mantellini 2019: 189–94). The collection of existing literature, the recovery of archive material, remote sensing and analysis of historical cartography, targeted geo-archaeological field investigations, and laboratory analyses have been the background of this study. During all phases, the research has largely benefited from the use of digital technologies and GIS for data collection, management, processing, and analysis (Mantellini *et al.* 2011; Rondelli and Mantellini 2004; Rondelli and Tosi 2006).

The first phase of work involved the analysis of satellite images, aerial photos, and Soviet military cartography (Mantellini and Berdimuradov 2019: 2–4). Satellite photographs from the CORONA programme (Mantellini 2017: 16; Mantellini and Berdimuradov 2019: 3–5; Mantellini *et al.* 2011: 391; Rondelli and Mantellini 2004: 37) and large-scale maps produced by the Soviet military services were an invaluable resource in identifying the anthropic evidence present in the territory of Samarkand. The reasons are various. First, the high resolution and detail of these datasets and the possibility of superimposing them with extreme precision as information layers in the GIS. Secondly, the high accuracy of the topographic series. Maps at 1:10,000, 1:25,000, and 1:100,000 scale are particularly remarkable because they reported the main

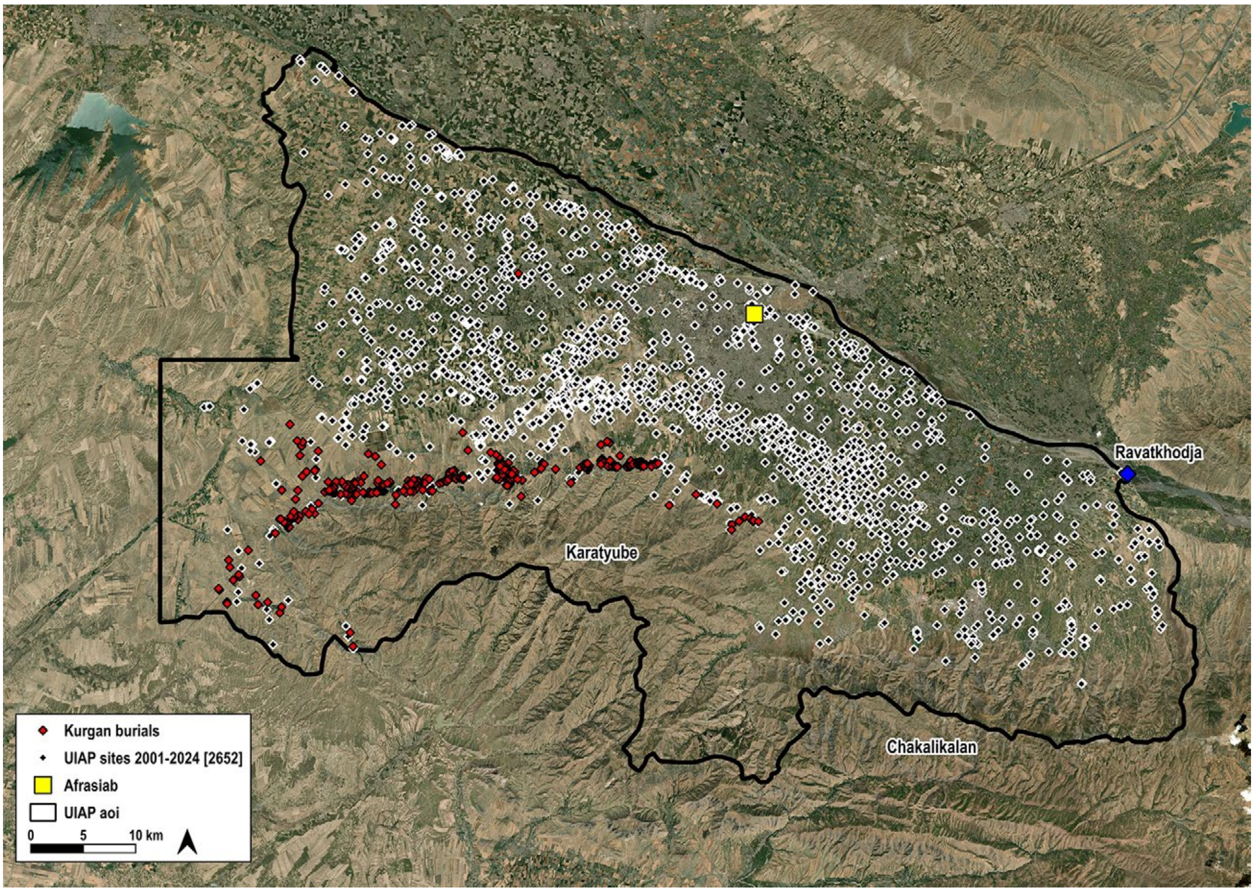

Figure 2. The UIAP archaeological map at the end of the 2024 season (basemap: 2024 BING satellite imagery; © UIAP 2024)

archaeological evidence (*tepa*) as 'anomalies' in the terrain and as such represented them through specific symbols (Mantellini *et al.* 2011; Rondelli *et al.* 2013: 388–90). Thirdly, the datasets provide a representation of the territory in the 1940s-1960s, i.e. before the great transformations caused by agricultural expansion linked primarily to cotton, and urban expansion of Samarkand and smaller centres.

The desktop assessment led to the identification of anthropogenic evidence, mainly topographic (archaeological mounds) and linear (canals), which then required ground truthing. Their subsequent validation in the field, possible thanks to the known coordinates for each feature mapped within the GIS, combined with the identification of other evidence reported by locals or belonging to different archaeological classes not detectable through remote datasets (flat sites, low mounds, *kurgan* burials) resulted in 2,500 archaeological records (**Figure 2**).

The most attested class is represented by multi-layered anthropic mounds (*tepa/tepe*) which mostly refer to sedentary occupation with different functions (residential, military, productive, etc.). Alongside flat sites (sherds scatters), low mounds (anthropic mounds <1m high with a short-term/single-period occupation), and negative evidence (canals), *tepa* were always connected to the presence of settled communities practicing irrigated agriculture (**Figure 3a**). On the contrary, stone structures similar to the low mounds (<1m high) but marked on the ground by stones arranged in circular or elongated shape and largely attested in the piedmont zones, can be interpreted as funerary *kurgans* or landscape markers associated with the semi-mobile pastoral communities in the rain-fed foothills (**Figure 3b**). The piedmont area is not very suitable for agriculture, and this has allowed the preservation of most of the necropolises. However, on the other hand, the archaeological material on the surface is almost absent, thus making any dating of the necropolises impossible in the absence of targeted stratigraphic investigations.

The first noteworthy observation concerns the high level of destruction of the anthropogenic mounds (*tepa*). The field inspection has in fact highlighted how approximately 40% of the *tepa* identified during the desktop assessment have been erased. Because of their volume, they occupied cultivable land and therefore

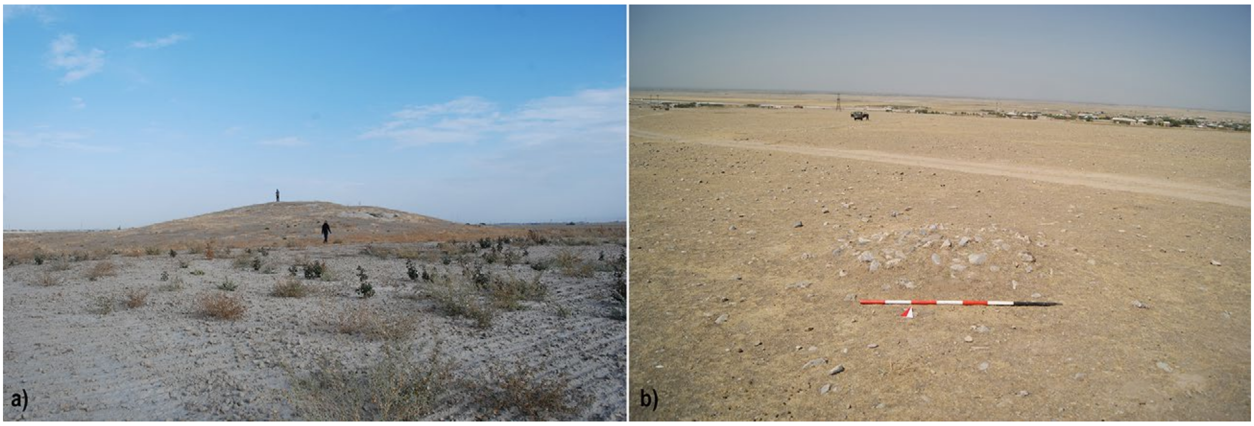

Figure 3. Example of archaeological record in the Samarkand oasis: a) multi-layered anthropic mound (*tepa*) in the present-day steppe (Sam-150, © UIAP 2010); b) funerary burial (*kurgan*) in the Karatyube piedmont (Nur-189, © UIAP 2021).

represented an 'obstacle' to be removed (Mantellini and Berdimuradov 2019: 9).

The finds (mostly pottery) gathered in the field make it possible to trace the major historical settlement development of this region (**Figure 4**). The uncertain chronology of many ceramic forms, especially those pertaining to the transition period, just permits some considerations in terms of historical-cultural horizons rather than dating to accurate centuries (Mantellini 2018: 180-181.). Although Samarkand was founded in the Achaemenid period (late 6th century BCE), the number of coeval sites is very small in its territory. The settlement growth began with/soon after Alexander (4th century BCE), it increased significantly in the post-Hellenistic centuries (3rd-1st centuries BCE), and it reached its height in the pre-Islamic centuries (6th-7th centuries CE). Despite the reduction that followed the Arab conquest of the early 8th century CE, the settlement remained stable under the Samanids and the Karakhanids (9th-12th centuries CE). A remarkable drop followed the Mongol conquest in 1220, when early Samarkand was entirely abandoned, while a new revival of the city and its surroundings is attested under the Timurids (14th-15th centuries CE).

Samarkand Waterscape

Observing the Samarkand oasis from space, a hydraulic landscape emerges as a result of complex water management over time (**Figure 1**). The Samarkand oasis develops along – and thanks to- the Zeravshan, which is the third longest river in Central Asia (700+km) and the dominant water feature in this region. Just North of the Chopanata hill, the Zeravshan splits into the Karadarya (from Turkish, 'black water') at the North and the Akdarya (from Turkish, 'white water') at the South. Local seasonal streams (*sai*) descending from the mountain slopes to the South and North have an intermittent flow rate, which is too limited to ensure a stable hydraulic supply (Mantellini 2020).

After Pendjikent, in Tajikistan, which marks the passage between the upper and middle river valley (Fedchenko 1870; Gentelle 2003: 127–69; Sadykov 1979), the Zeravshan expands (1.5km) and flows in the center of the floodplain. Its terraces on both sides represent the fertile background of the Samarkand oasis. However, to make its water available, it is necessary to build an upstream intake and divert the water into artificial canals that distribute the water throughout the entire territory (**Figure 5**).

Now, as in the past, the irrigation system of the Samarkand oasis originated at the small village of Ravatkhodja, ancient Waraghsar (Mantellini 2015: 1–4; Mukhamedjanov 1972). Since the first half of the last century, the 'May 1st Dam', now 'Ravatkhodja hydraulic infrastructure', has performed the fundamental function of regulating the waters of the Zeravshan and distributing them on both sides of the river (Sadykov 1979: 143). The reinforced concrete hydraulic structure replaced a traditional system built by 'tongues' of earth that entered the river to capture its waters and channel them into artificial canals. These earthen strips were stabilized by wooden tripods (*sepaya*), filled with river pebbles, wood, and heavy material. This system, still used to protect some villages near the Zeravshan (di Cugno *et al.* 2013: 100–102; Mantellini 2015: 4), was however light and subject to breakage during the seasonal floods of the river. Memory of it survives in some historical photos collected in the small museum inside the dam administration office.

In Samarkand, and in general in the semi-arid regions of Central Asia, the most common hydraulic work are

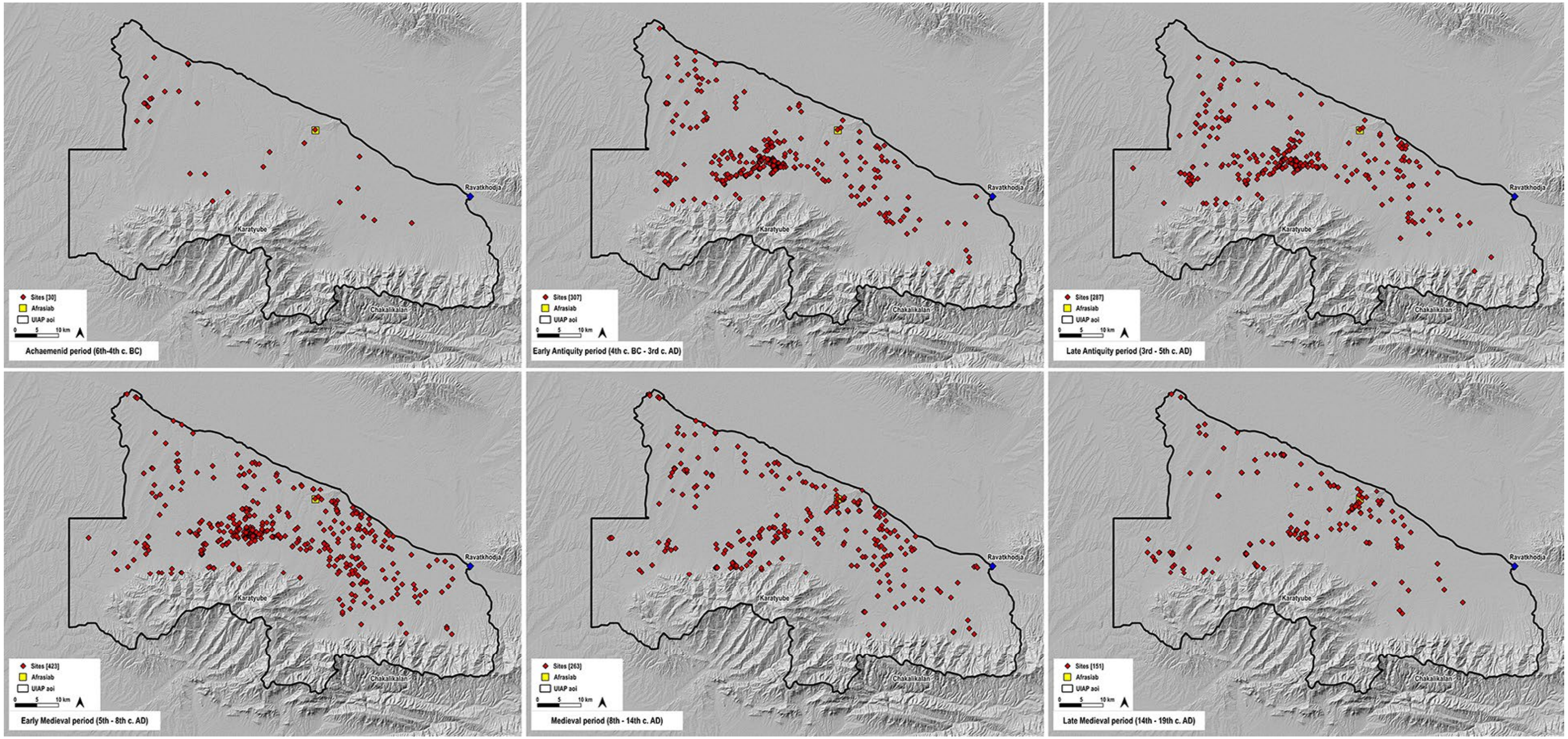

Figure 4. Settlement development in the Samarkand oasis from the Achaemenid period (top-left) to the Late Medieval period (bottom-right)(basemap: ASTER GDEM 2011, © UIAP 2024).

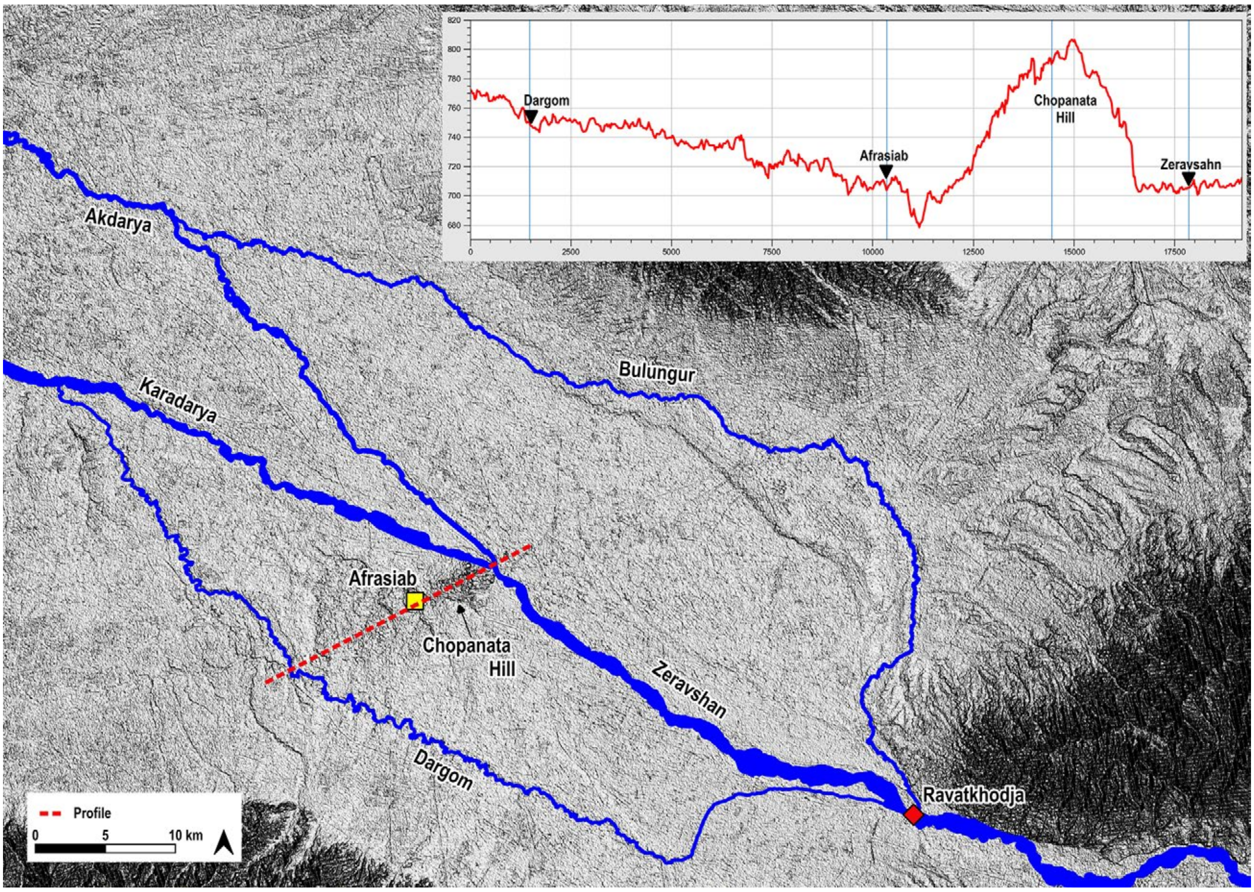

Figure 5. The artificial '*mesopotamias*' in the Samarkand oasis, and the altimetric profile between Dargom and Zeravshan (x = distance, m; y = elevation m asl).

artificial canals. Two canals are historically important for the hydraulic history of this region, the Dargom in the south and the Bulungur in the north (Gentelle 2003; Mantellini 2015; Stride *et al.* 2009: 75–80). Both canals originate in Ravatkhodja, and after supplying their respective territories with water, they rejoin the main river (**Figure 6**): the Dargom after c. 100km in the Karadarya, the Bulungur after c. 120km in the Akdarya. Similarly, the two canals circumscribe portions of territory (530km² to the south and 850km² to the north) and form a sort of '*mesopotamia*', or 'between the rivers' but they have a substantial difference today. Except for the first stretch in the Taylak district, the Dargom is now connected to the water supply of the urban area of Samarkand, which has been increasingly expanding in recent decades, while the Bulungur maintains its vocation as a canal for agriculture.

The artificial canals are the basic unit of a complex system that involves the use of other devices depending on human needs and morphology. Water wheels - the traditional wooden ones have been replaced by metal, allow the lifting of water from the main canals to the minor canals, and from these to the small ditches (*aryk*) that lead water to individual fields and plots. The flow of water in the minor canals is regulated by distributors and sluices, manually operated by the farmers according to their needs. A last element very widespread in the waterscape of Samarkand, both in the countryside and in the city, are the basins/ponds (*khaus*). The main function is to collect both rainwater and water from the canals and store it for more or less long periods, and use it for agriculture, animal and domestic needs. Being usually surrounded by trees, the *khaus* also ensure refreshment in the torrid summer months.

Alongside canals, different solutions have been used at local level based on ecological differences and water availability. In the piedmont and mountain villages, for example, wells are used in individual housing units, or water is often collected in the stream and then transported in containers by animals (donkey or horse). Only one case of a historical dam is known in the Karatyube piedmont (750m asl), the Gishtband dam along the Kattasai (Karasai according to the maps) between Djam and Karagaza villages. Its function was to regulate the water flow of the local stream. Initial research conducted in the 20th century allowed the structure to be dated to the Medieval period

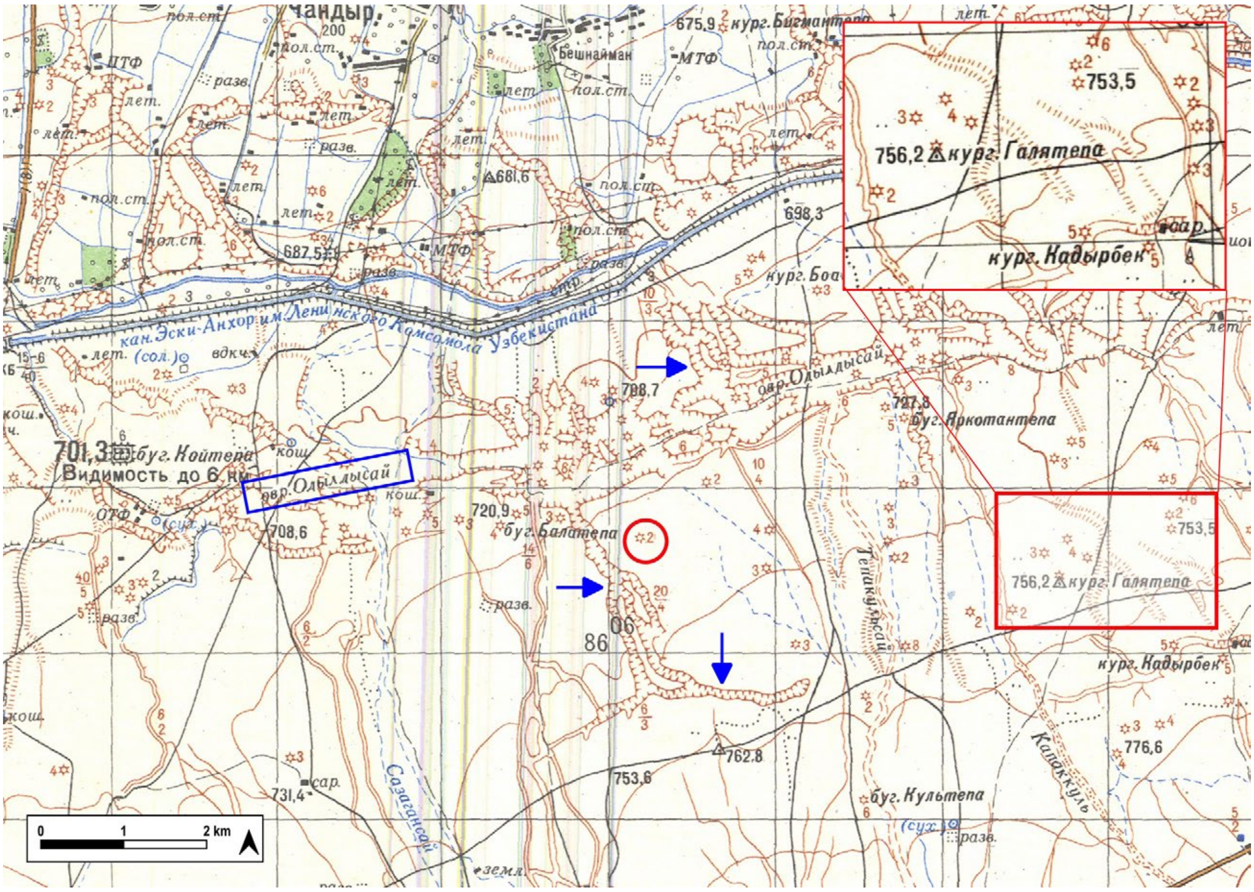

Figure 6. The well-preserved archaeological landscape in the present-day steppe of Samarkand on a 1:100,000 scale topographical map (J-42-014 Samarkand SO, 1972). Example of ancient settlements (tepa) inside the red markers (number beside symbol refers to the mound height – m), blue markers refer to palaeocanals, Odyldydai = ancient Dargom (© UIAP 2024).

(Mukhamedjanov 1966). Two UIAP inspections in 2019 and 2022 reported this structure as present, although its stone masonry was heavily altered by the lack of maintenance.

Studying the canals

From its very beginning, the UIAP has directed its research towards understanding the settlement dynamics in relation to the transformations of the territory. Thus, one research line has specifically concerned the study of the irrigation system, the Dargom in particular, for several reasons (Mantellini 2003). First, it is the canal directly and historically connected to the water supply of the city of Samarkand. Second, and partly connected to the above, its origin and development have attracted the attention of scholars since the last century. It is no coincidence that, in the paucity of written historical sources that characterizes Sogdiana in the pre-Islamic era, the only information relating to the canals concerns precisely the Dargoman ('long river') - plausibly the Dargom, which in Ptolemy's Geography is cited as the main water supply for Samarkand (Genito 2014: 26-27; Mantellini *et al.* 2009: 26-27, 2015: 5). After the Islamic conquest, and the increase of information reported by Arab geographers, the Dargom often appears - under a different name - together with other canals of the Samarkand region (Barthold 1928). Finally, not only does the Dargom appear consistently in written historical sources, but it is still the canal that feeds Samarkand. For this reason, scholars and locals share a sense of continuity between the history of the canal and that of the city.

Leaving aside the main question about the reason for hydraulic work, the main aims of the research concerned the construction technique and the time the Dargom was built. The latter is also closely connected to another aspect, namely the people behind the construction of such an impressive canal. The social component is the most difficult to establish due to the gaps in knowledge of some historical periods due to limited historical information and an equally poor response in the archaeological record (Mantellini 2018:

179–83). On the contrary, the construction technique and a first hypothesis on the dating of the hydraulic network of the Samarkand oasis are possible thanks to recent UIAP investigations.

Tracing the canals

As for *tepa*, CORONA satellite images and historical maps have proved essential for an initial mapping of the canals that once irrigated this territory (**Figures 6 and 7**). The identification of traces attributable to ancient canals has led to the recognition of now disappeared paleochannels.

The transformations that have profoundly altered the cultural landscape, and irreversibly erased much of the archaeological record, have affected the ancient irrigation system. The levelling of the land for agricultural purposes in the districts of Samarkand Selski and Nurabad has led to the complete burial of the canal beds. In other cases, only short stretches have survived and now, thanks to the collected moisture, they are ideal for grazing sheep and cows or for growing cereals. The most significant example is a short section of the ancient Yanghiaryk, which today can be seen for about 500m North of the village of Gulistan (1km on the 1980s topographic maps). The paleochannel, visited several times during the UIAP survey and at different times of the year was particularly green during the rainy season in autumn and spring, and thus was used for grazing cattle but occasionally also as a football field for local children (**Figure 8**).

Remote recognition resulted in the identification of numerous artificial canals. Those detected on maps and satellite imagery, and confirmed by subsequent field investigations are six at least. If today the main canals create large irrigated *mesopotamias* (Mantellini *et al.* 2011; Rondelli and Tosi 2006: 470), in the past the canals were parallel to each other and flowed at different altitudes in order to create irrigated bands that covered the entire southern oasis of Samarkand between the Zeravshan and Karatyube mountains (**Figure 9**).

Topographic maps have proven to be particularly useful to understand the hydraulic engineering

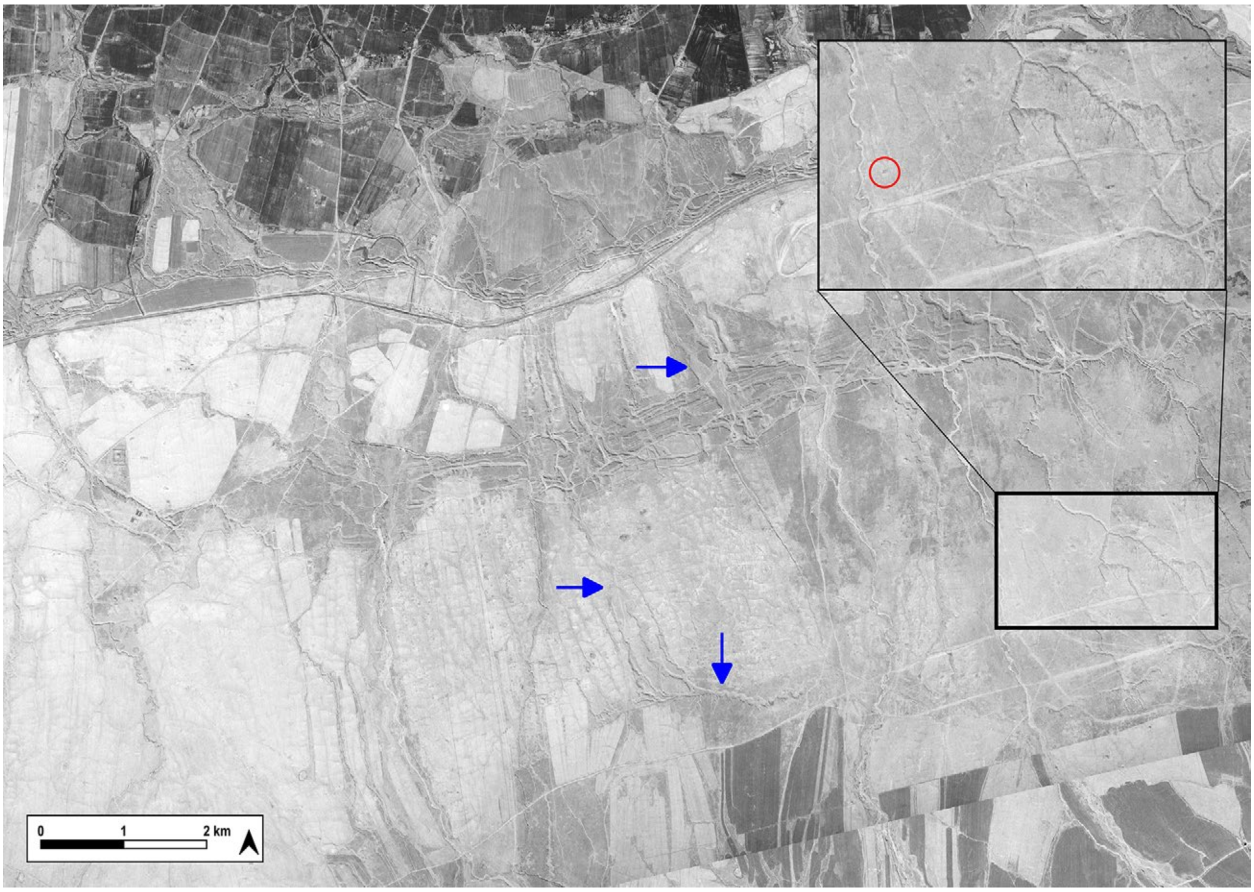

Figure 7. The well-preserved archaeological landscape in the present-day steppe of Samarkand on a CORONA satellite image (ID DS1011-1039DF128, 8 October 1964). Example of ancient settlements (tepa) inside the red circle, blue markers refer to palaeocanals, Odyldydai = ancient Dargom (© UIAP 2024).

Figure 8. The abandoned bed of the ancient Yanghiaryk canal (© UIAP 2013).

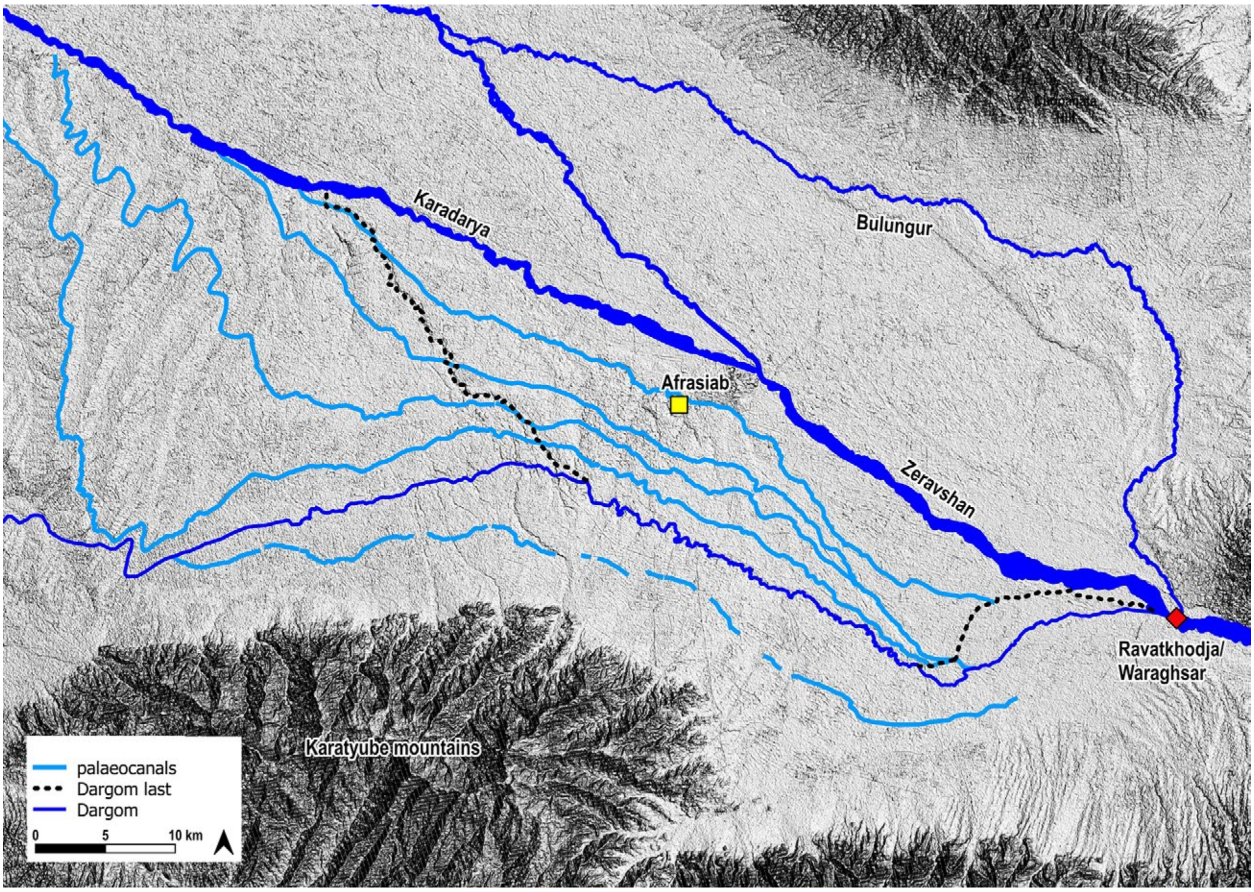

Figure 9. The reconstruction of the irrigation system of the Samarkand oasis, with the evolution of the Dargom canal (blue = original course; black dots = later changes) on an ASTER GDEM 2011 (© UIAP 2024).

behind the construction of the Dargom. The extremely detailed large-scale maps show how at several points the Dargom interrupts with its prevalent East-West course the piedmont streams (*sai*) that flow from the South following the natural orographic slope and then descend to the valley and subsequently probably originally reached the Zeravshan. The locations where the Dargom cuts these natural streams corresponds to the area historically affected by human settlements and related cultivation. The traces of the piedmont streams downstream of the Dargom are therefore detectable in the historical maps of the 1950s, albeit only in a few cases but they are a clear indication of the engineering behind the excavation of the canal. This same pattern was certainly also followed by the other canals parallel to the Dargom, but even in these cases the cultivation and urban development of the last decades have erased every trace.

The Dargom has been the subject of numerous investigations in the past, without however reaching a shared conclusion on its date. The hypotheses on it vary from the Achaemenid period to the Middle Ages (see a summary in Isamiddinov 2002: 15–30; Mantellini 2015: 4–6). The artificial nature itself has been questioned (Masson 1972) due to the meandering shape that makes this canal more similar to a natural river. The main problem is that many scholars have focused on the modern Dargom, which has little or nothing to share with the ancient one.

The Dargom is undoubtedly the canal that has left the most impressive traces, and that best exemplifies the hydraulic transformation that has occurred over time. Its paleochannel is well preserved today in the current *Pridargomskli stepi* (from Russian, 'steppe around the Dargom'), despite the agricultural works in progress that are completely transforming this area which was unexploited until a few years ago. Observed on any aerial image, the Dargom paleochannel stands out for its magnitude as a monument, and this was most likely the reason for its preservation until now. At that point, the Dargom has a width of c. 1km and it was shallow (its original depth cannot be established without targeted stratigraphic soundings). The canal was not completely empty between its levees. The earth savings, which look like small dunes, are probably intentional both to avoid very expensive excavation and to leave more crossing points between the banks given the width of the canal.

The original bed of the Dargom survives only there, recorded on the maps as Odyldysai (Mantellini 2015: 6). Further downstream, it was reused at the beginning of the 20th century for the modern Eski Angar. Further upstream it has disappeared. At a certain point, the western stretch of the Dargom (near the present-day centre of Kishrau) was abandoned in favour of the stretch, still existing, which follows the natural course of the Agalyksai and then reconnects with the Zeravshan. The reasons for, and the period of this change could find an explanation in the hydrographic changes following the Islamic conquest of the early 8th century, when it is known that the Arab troops broke the water intake of Waraghsar (present-day Ravatkhodja) causing damage to the watercourses and the territory (Barthold 1928: 191; Mukhamedjanov 1994: 272).

Confirmation that today's Dargom is different from the ancient one comes from further geoarchaeological investigations conducted around the major site of Kafir Kala (**Figure 10**). In its initial present-day stretch, the Dargom is narrow (average 40-50m) and several meters deep, and has nothing to share with the one visible in the steppe. However, the 2001 test trench at Kafir Kala, between the northern *shahristan* and the left bank of the Dargom, highlighted the presence of its sediments close to the *shahristan* itself, i.e. 50m from the present-day bank. The original riverbed of the Dargom was wider and at a higher altitude than the present situation (Malatesta *et al.* 2012: 95; Mantellini 2003: 44). Further geological sampling at the Kafir Kala site, at the nearby Sam-174 site, and at the village of Nayzatepa

Figure 10. The abandoned Odyldysai/ancient Dargom near the Agaliksai (© UIAP 2010) and the present-day Dargom near Djumabazar (© UIAP 2009).

confirmed that the right levee of the Dargom extended well beyond the current one, 100-400m compared to today's 40-50m (Marconi *et al.* 2009).

Having confirmed the artificial nature of the Dargom, and its original size, a combined use of archaeological records and radiocarbon analyses was employed to establish its dating (Malatesta *et al.* 2012; Marconi *et al.* 2009). Dating hydraulic infrastructures is a challenging topic, especially in the absence of information from multiple and reliable stratigraphic contexts, but possibly achievable through absolute dating. The latter, especially related to investigations conducted on a local scale at Kafir Kala and the nearby site Sam-174, indicated a long-term dating that testifies to the role of this canal in the history of the region. The chronological span ranges from the 2nd century (sample Sam-174 #1) to modern times. The earliest chronology, which refers to the same period in which Ptolemy mentioned the Dargom, is currently the absolute *ante quem* dating available. However, the environmental and climatic conditions of this area make it difficult to explain the massive proliferation of settlements in this region already in the Hellenistic period without an appropriate water management system. The current steppe, where the highest concentration of historical settlements and relics of anthropogenic canals have been identified, is a clear example of how in that environmental context life and agriculture are not possible without canals. So, at the moment, the most convincing hypothesis is that the irrigation system(s) of the Samarkand oasis originated precisely in that historical period (Mantellini 2020: 78).

Land use

The accurate recognition of human settlements and artificial canals thanks to multiple high-resolution spatial datasets allows us to hypothesize with a certain reliability the potential use of the territory in the past.

The network of artificial canals and the impressive number of settlements (*tepa*) testify to an intensive use of the plain. Unfortunately, the archaeologically excavated sites in the area with the most evidence (current steppe) are few but at the moment they confirm this hypothesis. The Sam-486 low mound at the Kurgan Kadirbeg complex, excavated by the UIAP in 2012, and despite its name was a small settlement of farmers (Mantellini 2017: 17, 2019: 198). The excavation has returned little architectural evidence and a large number of stone tools (millstones, pestles, mortars, etc.) for the processing of cereals. The small settlement was functioning for a short period and had a major occupation in the 2nd-1st centuries BCE (Mantellini 2019: 198-199). On the contrary, the site of Kojtepa has been systematically excavated since 2009 by the Uzbek-Italian expedition of the Samarkand Institute of Archaeology and the University of Naples L'Orientale currently directed by Bruno Genito and Mukhtar Pardaev (Abdullaev and Genito 2014; Genito and Pardaev 2020). The research revealed a long occupational continuity, from the 4th century BCE to the 10th century CE (Raiano 2014:297-302, 2020) and many evidences that indicate an important agricultural economy, and perhaps an 'hydraulic' role for this settlement (Mantellini 2020).

The highest canal found (800m asl), the Yanghiaryk, represented a limit between the cultivated and densely inhabited area. A first altimetric band (800-900m asl) is devoid of archaeological evidence, and this suggests that it was exploited for the breeding of sheep and cows according to a practice common even today. They are communities of shepherds who live in villages along the small alluvial fans of the piedmont and use the low pastures in winter and practice transhumance in the mountains in the summer months. Further upstream, there are about 20 large mounds used for habitation (*tepa*), while there are many low mounds (<1m high) covered with stones and interpretable as funerary *kurgans*. The impressive number (hundreds) of necropolises along the piedmont belt (800-1000m asl) is disproportionate compared to the few settlements, and it is therefore conceivable that the inhabitants of the agricultural settlements downstream were also buried there.

Conclusions

The irrigation system of the Samarkand oasis represents an exceptional case of hydraulic engineering over the long term. Due to its complexity and magnitude, the network of artificial canals and the related hydraulic infrastructures developed since ancient times stands as monumental evidence in the cultural landscape of this territory.

Some aspects such as certain dating of the Dargom and other canals, and the hydrogeological (and perhaps historical) dynamics that led to the change in the course of the Dargom are still open and under study. However, the integrated research approach used by the UIAP has made it possible to reach the first safe conclusions on the construction technique of the canals, a more limited chronological definition than the hypotheses formulated in the past, and above all revealed a hydraulic landscape articulated on a regional scale. The construction of the canals was necessary for the water supply in a semi-arid environment, and functional to the development of irrigated agriculture. The layout of the hydraulic infrastructure, settlements, and necropolises, and the 'void' of evidence referring to areas intentionally left free for grazing, indicates a precise territorial plan functional to an agro-pastoral economy where historically irrigated agriculture is the prevalent economic source of the Samarkand oasis (Mantellini 2019: 199).

Acknowledgments

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Chapter 10.
The Archaeology of Water Management on the Swahili Coast of East Africa

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Introduction

On the East African coast, water management remains a largely understudied topic, at least in comparison with other regions of the Islamic world. The reason for this debt in research may be predetermined, among other things, by the fact that no large-scale water works or irrigation systems visually dominate the built heritage landscape associated with Islamic settlements in this part of the world. The sites of coastal towns of the Swahili culture that characterised the coast from the 8th century (all dates are CE unless otherwise specified), however, demonstrate significant achievements in water management in the course of their histories. These may be analysed especially on the basis of architectural features built of coral stone that were widely constructed on these now deserted sites between 12th and 17th centuries and that preserve to today. The Swahili had to deal with scarcity of freshwater in a relatively arid environment, as well as with great seasonal differences in water accessibility, and yet local water management successfully supported complex urban settlements that would have depended on reliable freshwater supply and required water to be available in numerous specific settings and for a range of uses. Although there were periods of oscillating density and changing longevity of these settlements, the local trajectories of urban way of life have remained on the whole unbroken from the precolonial era to today. There are still significant gaps in research that strives to understand the foundations of local resilience, and studying water management is one of the perspectives that could certainly help shed light on the issue.

Research is further complicated by the lack of long-term perspectives that would reflect on and contrast different periods in the history of the coast. While archaeology, specifically, has been mainly concerned with the precolonial period mostly up until the 17th century, disciplines such as ethnography, urban studies, as well as natural sciences focus on present-day water resources and social role of water and rarely consider the precolonial past. This chapter aims to contribute to bridging the gap given by disparate disciplinary focus and demonstrate that archaeological data may inform present-day water management, and vice versa, that contemporary experience has the capacity to enhance our understanding of the precolonial past. To achieve this goal, this paper reviews evidence on precolonial water management from several archaeological sites and reflects on present-day knowledge and communal water management as it is practiced in living small-town/village communities in the vicinity of these now deserted settlements.

In Swahili archaeology, the theme of water management has mostly been addressed as a cause for explaining the abandonment of Swahili towns, thus implying that it was only when people failed to obtain sufficient freshwater that water management significantly impacted on the life of coastal settlements. However, this study examines the rich material culture evidence that active engagement with water was part of daily life in the past, and that it not only accompanied but facilitated a range of social and religious practices, representing a distinctive part of the Swahili culture.

In this chapter, the review of approaches and solutions employed in water management that are typical for the precolonial period is based on a summary of research published about the East African coastal sites, considering capacities of the natural environment, as well as on data derived from research of the author on two case study regions in Kenya, one located around Mtwapa Creek near Mombasa and the other in the Mida Creek region close to Malindi. The relevance of water management is traced here as intertwined in social life, considering in turn how water has been accessed, stored, distributed and used, while addressing the connotations of water management on life-cycles of the towns. The paper also aims to identify priorities for future directions in archaeological research that could advance the archaeology of water further, and considers how this could benefit present-day life in the coastal environment.

Freshwater in East African Islamic towns

Geographical setting and the natural environment

The East African coast may be characterised geographically as one of the regions located on the periphery of the Islamic world. Although the vast stretch of the coast that spans approximately 3,000km in length would seemingly imply an obstacle to communication, the opposite has been the case, judging on the basis of archaeological, anthropological, linguistic and historical data. The Swahili culture, which has given the coast its alternative name, has been characterised by building trade links extending along the coast and beyond to the African interior and across the Indian Ocean to the Middle and Far East. Over centuries, strong cultural similarities or parallels were constituted along the coast that is today divided into Somalia, Kenya, Tanzania, northern Mozambique and northern Madagascar, and includes numerous offshore islands and archipelagos (**Figure 1**). The shared preferences and styles are apparent on the locally-made material culture such as ceramics and other portable objects, popularity of material culture imported through long-distance trade, as well as in the built environment and settlement types. Water management was a part of the Swahili culture, and as such, material culture associated with water also has shared features identifiable across the coast (Baumanova 2023a). Although over the last millennium Swahili culture was shaped and transformed from the inside as well with external influences, including colonisation from the Arabic Peninsula and from Europe, it remained interlinked and kept a certain 'shared rhythm', developing lifestyles that have a lot in common along the coast and cut across the present-day state boundaries.

These historical trajectories also reflect how the natural environment set the limits to the water management on the coast. As it is often the case across the Islamic world, the East African coast is a relatively arid environment in terms of availability of freshwater, as least with regards to groundwater sources. There are two seasons with rainfall – the long rains come in the spring from March to May and the short rains approximately in November to December, so it is important to note that the aridity has a seasonal character, setting the coast apart from, for example, the core regions of the Islamic world in the Middle East.

There are few rivers, streams, or lakes, and the immediate neighbouring landscape offers no alternative sources of groundwater, such as highlands or mountain ranges that are exploited further inland along the Rift escarpment (Sutton 1989). The larger river deltas, especially of the Tana in Kenya and the Rufiji in Tanzania, were settled for millennia, but as for the recent centuries, evidence does not suggest that settling in the deltas would have been preferred in favour of other locations along the coast; rather there might have been preference for establishing Swahili towns on islands, near inlets and on the edges of zones facilitating interaction with other social groups such as the Mijikenda, Oromo, Taita or Waata (Kusimba 1999; 2024). Many towns were positioned directly on the beaches, allowing access to trade networks of the Indian Ocean and to maritime resources. The proximity of settlements to seawater, however, had influence on freshwater management, as the water table of freshwater and saltwater oscillates and is affected by short-term periodicity such as the weather or change of seasons as well as by longer-term factors like change in vegetation cover, seawater intrusion or climate shifts (e.g. Idowu *et al.* 2017; Mahongo and Shaghude 2014).

Water management is interlinked with a specific building material used in construction of water features – fossilised coral. This local type of limestone that was used in construction very much until the overwhelming adoption of concrete was quarried from the ocean or on land. While in the built environment we may find structures of this stone as well as of mud and thatch and a combination of both, the use of stone was paramount for construction of water features. It can be stated that built features associated with water management were significantly out-scaled by other structures in the Swahili built environment, such as mosques, great houses, or tombs, because no monumental cisterns, *qanats* or large-scale irrigation systems have been discovered. However, the importance of water-related construction in Swahili context may be derived from the fact that along with the town walls, waterworks represent the only type of construction projects that must have been as least in some contexts communal, in the sense that multiple households needed to collaborate for the urban system to work.

The use of coral for building facilitated construction of permanent features, such as wells. However, this building technology requires relatively large quantities of freshwater. The most notorious obstacle in building with fossilised coral and lime stems from the ever-present salinity in the environment. Wynne-Jones and Fleisher (2014) claimed that in the construction process, salt needs to be washed out from lime with a significant amount of freshwater. This may have been provided by seasonal rains instead of water from wells. For finished standing structures, salt crystallisation is the greatest threat as it causes structural deterioration as well as loss of water-resistance of the walls. With all this in mind, a

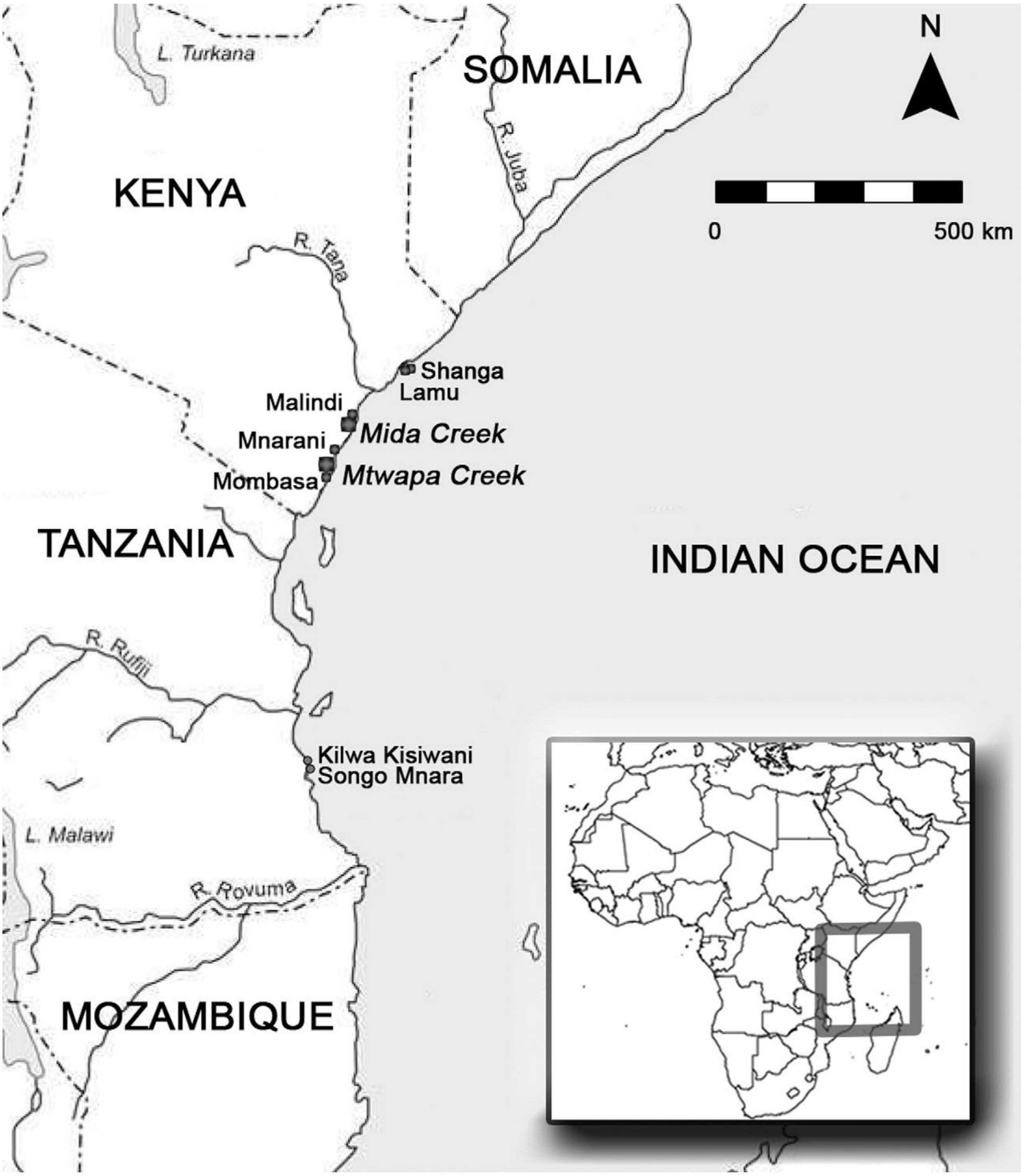

Figure 1. Map showing the location of the two study regions, Mtwapa Creek (the sites of Jumba la Mtwana and Mtwapa) and Mida Creek (the sites of Gede/Gedi, Kilepwa/Kirepwe and Shaka), discussed in the text, as well as some other important sites.

range of choices made in construction may be put in context with the effort to protect stone features from salinity and seawater over time. For example, these include the effort to prevent capillary action that may be used to explain the preference of building on rocky outcrops, the annual re-plastering of building faces, or the historically recorded use of *murrapa*, a plant which is soaked in water for the resulting solution to be mixed in plaster in order to make it saltwater-repellent (Berti 2016).

Islam and water use practices

Apart from the geographical setting and capacities of the natural environment, Swahili water management was shaped by religious practices and faith in general. The importance of Islam for the region is attested relatively early on, as it started to be gradually adopted by local communities from the 8th century (Horton 2004). As opposed to other parts of the Islamic world, North Africa for example, where expansive spread of the faith was promoted, encouraged or forced, it is a characteristic feature of the East African coast that once Islam was adopted by the Swahili, it did not spread further inland to other communities and the distribution of Swahili towns has always remained limited to the oceanfront. Likely, this was a social strategy, when the Swahili people were safeguarding their unique 'middlemen' role in trade between the Middle East and the African inland (Suzuki 2018).

It needs to be considered that adopting Islamic practices was likely associated with specific demands and preferences in local water management. Today, Islamic settlements and towns are specific in their water management strategies, as well as in practices determining the form in which water is kept, distributed, and used. Religion is associated with choices related to placement and frequency of cleaning activities, water use customs as well as with demands in the form in which water is available. Islam is characterised by preference for 'running' or 'pooling' water, that is encountered in specific contexts, as it may be demonstrated by the frequency of water features on house courtyards across the Islamic world or by ablution pools by mosques (Saitta 2022). Zenani and Mistri (2005) contrast Islam with Hinduism to highlight how these religions require water in different times of day or during religious festivals.

Since the time Islam was adopted in coastal towns, water management was likely affected by the relevant prescriptions of the faith, such as conducting bodily practices like cleansing that are believed to cultivate behaviour (Mahmood 2005: 139), or the general guidance to avoid wasting water (Smith and Ali 2006), which means water might have been recycled for irrigation of gardens.

With these considerations in mind, water management in Swahili context must have at least to some extent contrasted with those of neighbouring communities, none of which adopted Islam. Within Swahili houses, for example, this might have been reflected in requirements placed on cleanliness during activities for which practical availability of water within the houses is necessary (Donley-Reid 1990). Ethnographic data attest that individual rooms of houses are associated with different level of cleanliness, and it is also considered a necessity to have a latrine located inside the house (Middleton 2004: 46). Data from any archaeological site on the coast confirm that latrines were commonplace in stone houses of the precolonial era.

In the precolonial towns, a lot of religious activities required relatively large quantities of water. Archaeological data show that there were usually multiple mosques that may have been smaller in size but nearly always had ablution pools. This is also exemplified by mosques at sites in the case study regions discussed in this paper, such as Jumba la Mtwana, Mtwapa, or Gede. Smaller mosques may have had just a small pool, or water might have been directly drawn from a well or supplied from water jars. Following Islamic guidance, it may be expected that it was desirable for water in these pools to be pure, not 'grey' (Zenani and Mistri 2005), which explains the frequent association of the ablution pools with wells, as discussed below. Cleanliness and order were also represented in the regular re-plastering of buildings including mosques with lime, that renewed their white outlook.

The role of water in Swahili society

It may be derived that in the coastal environment groundwater is not easily available, yet large quantities of clean freshwater were needed to support the local urban lifestyle, even more so in the dry seasons. The problem of research on how this was managed throughout the last millennium is that daily practices associated with water and their transformation over time have not been in the spotlight of research. Rather, archaeology of water in the precolonial period has been dominated by considerations of the potential link between abandonment of a number of settlements in the 14th and 15th centuries and increased salinization of wells (e.g. Sassoon 1980; Wilson 1978/1979; Kirkman 1954; 1964). For the subsequent period, the processes that started especially in the 17th-19th centuries at the time of European and Omani colonialism, such as changes in water systems and development of irrigation, remain virtually unstudied, although it can be expected that a range of new approaches were introduced to the coast in this period. These changes included enhanced considerations of sanitation in context with significant population increase at least in some regions and towns. From the written sources referring to Zanzibar, for example, it may be derived that the most pressing issues were planning of sewage and higher-capacity drainage systems (Bissell 2011). Finally, water management has been the subject domain of environmental studies and urban studies in particular in the recent decades and to advise future development but has remained outside the scope of or dialogue with (ethno)archaeology.

The impact of the divided disciplinary agenda is significant. In archaeology, it has limited the discussion to site abandonment, as salinization of wells has been used as the primary interpretation of why some towns were deserted rather abruptly after a few generations or centuries of occupation. Considering there is little to no evidence of violence as a potential reason for abandonment of Swahili precolonial towns, there is still a range of other potential environmental and social reasons that have not been sufficiently discussed and that could explain why the abandonment and/or translocation of settlements is observed in such an extensive area all along the coast. For research on the contemporary coast, current studies deal with scarcity of water in coastal towns such as Mombasa, yet do not mention the fact that present-day water management is based on entirely different principles to what they were few centuries ago, and that today towns tend to draw larger quantities of water at fewer places that are supposed to sustain a relatively large area (Walraevens *et al.* 2015; Steyl and Dennis 2009; Edmunds 2012). Linking the knowledge on precolonial period and the present-day may hence be expected to bring important insights into the debate.

Case studies of precolonial water management

Data from many precolonial sites that has been collected over some 80 years of archaeological research on the coast may illustrate how water was managed in the precolonial era. Drawing on a number of these sites, here the focus is primarily on two regions with archaeological sites located in the vicinity of so-called creeks in Kenya, which are tidal inlets and represent a typical feature of the East African coast. The first area, Mtwapa Creek, is located in the vicinity of Mombasa by a small modern town of Mtwapa, and the second, Mida Creek, is located some 80 kilometres further north in the vicinity of the town of Malindi and in a direct neighbourhood of the small town of Watamu (**Figure 1**).

In each of the regions, multiple precolonial sites have been recorded, but it is likely that there were even more in the precolonial era. Sites with preserved standing features, including those associated with water management, are more visible and hence they have been to some extent documented or even partially excavated. Around Mtwapa Creek, there are the sites of Jumba la Mtwana and Mtwapa - the latter site bears the same name like the modern town in its vicinity. The occupation of both sites was likely overlapping for some time as Jumba la Mtwana is dated to the 13th-15th century (Kirkman 1974), while an earlier date of the 11th century has been confirmed for Mtwapa with abandonment at the earliest in the 16th or 17th century (Kusimba *et al.* 2018; Wilson 1980).

Mida Creek region is famous especially for the site of Gede (also known as Gedi), which is one of the largest sites on the coast that was also one of those occupied for the longest period of time from the 8th to the 17th centuries (Pradines 2010), while excavations there still continue. There are remains of multiple other sites in the region which are today represented by individual features such a mosque or the remains of walls, especially within the present-day town of Watamu, or by the few standing features that remain of the site of Shaka on the southern bank of the creek. There is a larger site of Kilepwa, which is also locally known as Kirepwe, that was occupied between the 12th-17th century (Kirkman 1952) and it is located on an island approximately in the centre of the large Mida Creek lagoon. Both regions were continually settled since the precolonial era, so it is not surprising that the settlement periods on all of these sites are to some extent overlapping, However, it is apparent that movement and possible relocation has been a part of local settlement histories and popular stories that one comes across in the area, and which are rich with narratives of communities or families moving from one town to another.

Architectural features such as house layouts, mosque design as well as features associated with water that preserve on these sites very well fit into the picture known also from other Swahili sites on the coast. In order to facilitate further discussion, structures associated with water management are classified below with regards to their purpose into those built for accessing freshwater, for storing and distributing it and finally for using water during regular activities.

Drawing water

The process of getting a sufficient amount of freshwater in Swahili towns depended primarily on a system of wells. Precolonial wells were always circular but had a varying diameter ranging between 1m to 4m. Within this quite broad range of sizes, there seems to be no preference for a particular size of wells at a single site either; rather sites usually feature wells of multiple sizes. In terms of possible correlation between the size and placement of wells, in the two case study regions larger wells were placed by mosques, probably for providing sufficient amount of water for ablution pools, while smaller ones were on public open spaces or located on house courtyards (Baumanova 2023a). The rim of a well was usually raised slightly above ground level (in the study region the rims preserve at the height between 10 to 50cm on average), and although many wells are at least partially filled-in today, it is apparent they varied greatly in depth, too (**Figure 2**). Three wells at Kirepwe/Kilepwa are today rather shallow, reaching 3-4m, while at Jumba la Mtwana and at Gede, several wells have at least 5-6m.

Figure 2. Examples of wells from Gede (Mida Creek) (photos. M. Baumanova).

There were also significant differences in the number of wells identified on individual Swahili sites. For example, at the site of Songo Mnara, Tanzania, less than one well per hectare was recorded (Wynne-Jones and Fleisher 2014: 254). At the site of Gede in the Mida Creek region, the core of the site with stone architecture has about two wells per hectare, and research at Jumba la Mtwana identified six wells per hectare (Baumanova 2023a). Generally, it needs to be taken into account that most sites have not been fully excavated, and it is possible that not all past wells were recorded during surface surveys. However, both the mentioned sites of Songo Mnara and Gede have been intensively studied and yet there are major differences in the overall number and density of wells.

This may be explained through several potential scenarios. Either, wells could have been yielding significantly different amounts of freshwater in individual locations as a result of the local geology of aquifers. Alternatively, there might have also been different social rights associated with the use of individual wells that might have resulted in different impetus to dig more or less wells. Considering the placement of wells at Gede and at Jumba la Mtwana, wells were distributed across the towns and situated in different contexts. Mosques in the region are always associated with a nearby well; wells were also placed in presumably private contexts in the courtyards of houses (**Figure 3**). Two to four wells on each site may also be presumed to represent 'public' wells, as they were located on open spaces and hence accessible publicly or at least by multiple households in the vicinity.

Third, rainwater needs to be considered as a major alternative source of freshwater. In terms of archaeological data, the practice of catching rainwater is best represented by cisterns. Contrary to the distribution of wells in a variety of spatial contexts, the placement of cisterns was usually limited to house courtyards or to the vicinity of mosques. Therefore, the variability in size, density of distribution, and placement of wells was complemented with diverse relevance and intensity of catching rainwater. The ratio of water drawn from wells and rainwater hence likely varied greatly site to site as well as between dry season to rainy season, and undoubtedly depended also on local tastes and preferences in water management strategies.

Storage and distribution of water

Apart from their role in collecting rainwater, cisterns were to some extent used for its storage. Keeping water clean in cisterns and open reservoirs was ensured through several mechanisms, such as keeping small fish that eat mosquito larvae as is seen along the coast today, or insetting bowls for collecting mud at their bottom, as it is attested in historical and ethnographic sources (Kamalkhan 2010: 146), as well as on archaeological sites, including Jumba la Mtwana and Gede. It is difficult to estimate the original volume of these cisterns because of the uncertainty about the original heights of their walls, but considering that these features preserve relatively well, the larger ones could potentially have a volume of a cubic metre. It can be presumed they were not full to the brim, so the amount of water held in them was smaller. The volume of cisterns was in many cases similar to the size of ablution pools by mosques, based for example on comparisons from Jumba la Mtwana, or the cisterns were slightly smaller.

In the Swahili built environment, neither cisterns nor ablution pools stand out in terms of size. Because the East African coast is a malaria region and large still surfaces of freshwater are not desirable as they provide breeding ground for mosquitos, this may explain the preference not to store water in larger open-air containers and not to keep it there for long. The fact that Swahili towns never had an abundant supply of

Figure 3. Examples of well placement at the site of Jumba la Mtwana (Mtwapa Creek). Top - photo of a well in a house courtyard; bottom – 3D model view of well by a mosque with an ablution pool (photo. M. Baumanova).

water that could be drawn to the towns is demonstrated by the lack of water features like long water canals and fountains that were so popular in many other Islamic regions of the Middle East or Iberia. While these water features in the Middle East contributed to the cooling of houses, on the East African coast this was achieved with air, by the positioning of courtyards and openings to facilitate air circulation, to catch the breezes from the ocean and to provide ventilation (e.g. Garlake 1966).

The element of running water was to some extent substituted by interconnecting individual water reservoirs with conduits and short water canals, that likely served to save people effort in carrying water from wells. These conduits were usually open and slightly raised above the ground. Beyond the case study regions, this was noted for example at Songo Mnara (Wynne-Jones and Fleisher 2014: 255) and a very-well preserved example may also be found at Mnarani (**Figure 4**).

Figure 4. Openings interconnecting two cisterns by the Small Mosque at Mnarani (photo. M. Baumanova).

Water from wells and cisterns was also stored in ceramic jars and there is widespread evidence of these across archaeological sites. Sometimes, as at Jumba la Mtwana, they preserve in-situ (**Figure 5**). Evidence of this type of ceramic jars has been recorded by cisterns, in courtyards, within rooms in houses, or in mosques (Wynne-Jones and Fleisher 2014; Kirkman 1963). It is complicated to estimate the average size of these ceramic jars when complete, but on the basis of some preserved examples it seems they could hold a volume of approximately 10 litres.

Water use

In context with daily water use on Swahili sites, cleanliness and personal hygiene are usually the most discussed themes. There is indeed abundant ethnographic data that provide parallels and stress the importance of clean rooms within a house or personal cleanliness at particular events (e.g. Donley-Reid 1990; Middleton 2004; Fabian 2019). The long-term relevance of these themes reaching to the precolonial period is attested by data from archaeological sites, where the wide availability of water shows that concepts of cleanliness as well as personal hygiene were accentuated in the precolonial Swahili society. For example, the presence of wells by each mosque shows that there was clearly an effort to ensure that all mosques have their own clean water supply. Personal cleanliness is also attested by footscrapers often associated with ablution pools that still preserve for example at Jumba la Mtwana or at Mtwapa. In private contexts, there is evidence for cleaning activities in the houses, such as the drainage holes recorded in the palace-complex at Gede (Kirkman 1963: 22). These holes that were built in the floor in the process of construction speak of the importance ascribed to regular cleaning. Most stone houses also had in-house toilets and lavatories, as apparent on all sites in the case study regions.

Water use is also associated with drainage and disposal of unwanted dirty water. Channels bringing water to lavatories next to latrines inside houses are preserved, for example, at the site of Gede. The evidence from Gede suggests that this arrangement was particularly important in house blocks, where houses were densely packed together. Here, conduits and channels for distributing water as well as drainage systems attest

Figure 5. The remains of a water storage jar from Jumba la Mtwana (photo. M. Baumanova).

collaboration between households. The only other type of feature in precolonial Swahili towns where this is clearly apparent are town walls, that at many places respected house distribution, constituted continuation of the walls of houses, and required each household to subscribe to the idea of building and potentially looking after a minor portion of town walls (Baumanova 2023b; Pradines 2004), such as those that are preserved at Jumba la Mtwana or Gede.

Finally, it cannot be ruled out that water was to some extent used for irrigation, but no evidence of irrigation canals or similar features has been recorded. This may be because such features, if they were used, were not built with stone. Rarely, such as for Jumba la Mtwana, it was speculated that one portion of the site where multiple cisterns, but no wells were identified could have had an agricultural purpose (Wilson 1980: 74). It could be argued that in this case rainwater was used for irrigation. However, for further debate and assessments, comparisons with the present-day situation may be useful here.

Present-day communal water management

A sample set of data on present-day water management was collected intermittently during the author's research between 2021-2023 on the basis of interviews with local people and observations taking place in the field. The focus of this information-gathering was on villages and small towns that are located in the immediate vicinity of the deserted precolonial sites in the two case study regions. Such data are likely to provide interesting reflections on the past because people here still live with a similar set of freshwater resources in the environment, which supports several hundreds or thousands of inhabitants, albeit the environment has changed to some degree over time.

It needs to be stated that the communities in the case study regions are composed of groups with diverse identities, not just the Swahili. For this reason and considering the significant social changes that the coastal settlements underwent over centuries, these towns do not represent a direct parallel with precolonial towns. Nevertheless, understanding

Figure 6. Modern well on the island of Kirepwe in Mida Creek, Kenya. The picture on the right shows that the well is placed just above of the water line at high tide (photos. M. Baumanova).

current water management at a community level highlights the specifics of the strategies that may have long-term histories. Namely, in the Mtwapa Creek, information was collected in the town of Mtwapa, and in the Mida Creek, from the settlements of Watamu and small village of Kirepwe on the island in the lagoon. The densely populated modern cities such as Mombasa are left aside in this paper, as no data were gathered there. The situation there has its own specifics and is not directly comparable with preindustrial sites.

Today, water on the coast is sourced from wells and from boreholes. While wells are generally dug without machinery in a community context, they are wider and shallower than boreholes. Deep boreholes are dug with machinery and as such they may reach lenses of freshwater located deeper below the surface, but they are also much more likely to cause their collapse and result in seawater intrusion, because the coastal sediments are relatively unstable (Edmunds 2012; Comte *et al.* 2016). The appearance of wells changed somewhat over time, as the above-ground portion of current wells may be either circular or oblong in shape (**Figure 6**), as opposed to the precolonial wells that were always circular. This may be given by changed preferences, customs, and different properties of cement and other modern materials that are used in construction today. The depth of wells still varies greatly and so does their distribution, and they are still dug relatively wide with a diameter of several metres.

On Kirepwe island, in a present-day village located in close vicinity of the ruins of the precolonial settlement, specific people in the community who have knowledge of the area are invited to select a suitable place for new wells, which are dug rather regularly, i.e. without waiting for water in the existing wells to 'turn bad'. The knowledge of people that can find a freshwater source is valued and not widely shared, and they may not necessarily come from the local island community. This information from local people correlates well with ethnographic evidence that well-diggers were contracted across ethnic and community dividing lines, and that for example the Oromo were known well specialists employed by the Swahili (Kusimba and Kusimba 2017).

As for placement of wells, local people state repeatedly that wells are dug in places from which the ocean is visible, as these wells tend to produce good water. Today, many wells are situated very close to the coastline, fitting well with the observation noted already in the 1980s that just above the highest seawater level mark is usually a good place for placing wells (De Vere Allen 1981). Here, a few metres in depth are sufficient for the well shaft to reach a freshwater lens that is lighter and sits on top of the seawater level.

The life span of wells varies greatly. In the town of Watamu which lies next to the site of Gede in Mida Creek, old wells have occasionally been cleared or re-used, but this seems to be a rare practice. When enquiring about possible re-use of wells on abandoned precolonial sites, the author of this paper was told that water from old wells tends to be brackish and that once a well is exhausted, it is better to dig a new well that need not be far away. The site of Gede is a National Monument, so local people could not use the wells in the area, but on Kirepwe island, the site is mostly overgrown so local people have unlimited access to it. However, even here people are aware of old wells on the site but would use none of them as they say their wells in the immediate vicinity would now give better water.

In the settlements where I conducted my enquiry, catching rainwater is not a common practice, apart from the island of Kirepwe where it is to some extent still used. But even here, water is now more commonly brought from the mainland. Buying drinking water is common and has been recorded historically along the Swahili coast (Bissell 2011), so water is recognised as a commodity, and water vending is usually a profitable business (Chowdhury 2009). However, today it may concern significantly larger quantities of water used for a variety of purposes apart from drinking. Today, water is bought and stored in plastic bottles or canisters that are easily transported on bikes, motorbikes, cars or boats. In the other region, pipe water is available in some parts of the town of Mtwapa, so rainwater is generally not harvested.

In terms of distribution, conduits for channelling well water are no longer constructed in either coral or cement in the study area. The question whether water is used for irrigation yielded interesting answers, especially considering the relative aridity of the environment. Irrigation from cisterns is used on small gardens by the houses. Some distance from settlements wells may be dug providing water for people, animals on pasture, as well as occasional irrigation of garden patches. Their use is not public in the sense that not everyone has the right to use them; for example, people from the mainland that come on boat for trade opportunities to Kirepwe island should not draw water from local wells, and in Mtwapa, which is a larger town, the author was informed that people have rights only to the wells in their neighbourhood.

Generally, having a quantity of water-resources and their diversification are understood as very important in both regions. The number of wells and use of purchased water, which ratio can shift easily as required, mean that the system of managing access to freshwater is very adaptable. Among the communities today, it is recognised as desirable to have more wells than a settlement needs with respect to the number of households, as they can be used at different times throughout the year or in specific years only when they are recharged. Seasonality during the year plays an important role. On the island of Songo Mnara in Tanzania, it was noted that in the vicinity of the precolonial sites, wells are known to be saltier in the dry season (Wynne-Jones and Fleisher 2014: 247). Changing chemical composition of coastal freshwater is confirmed by hydrological studies (Idowu *et al.* 2017). With regard to this question, local people in both regions generally agree that there are differences in freshwater supply and quality during the year, which is also a reason why the use of some wells may be seasonal.

Discussion

The phenomena described above have implications for interpreting data from archaeological sites as well as for informing decisions made in present-day water management. Data from precolonial sites in the two regions very well show the flexibility and variety employed in the strategies for gaining access to freshwater and in its use. In the precolonial era, groundwater from wells and harvested rainwater had to cover all the freshwater needs of the coastal towns, yet, no two sites were identical in managing the available water resources. This is apparent especially in the different relative ratio of rainwater and well water used, represented by the different densities of wells on precolonial sites ranging from one to six per hectare in the two study regions. These diverse strategies fit very well with the conditions along the coast that are described by current surveys of groundwater availability in coastal Kenya, Tanzania and the East African islands that show high variability and seasonality in distribution of groundwater resources accessible through manual digging of wells (Comte *et al.* 2016).

Seasonal changes in availability of water are also reflected in the preserved evidence from past Swahili towns. The uneven concentrations of wells and/or their close proximity on some sites, such as at Jumba la Mtwana where wells were distributed 10m apart, or in specific quarters at Gede, would have aided the diversification of freshwater resources. All wells were probably not used simultaneously, similar to the established practice today. It is likely that in the precolonial past, too, there were opportunities for trade in freshwater. Water could have been used as a commodity, access to which may be seasonally complicated, paid for, and not easily available to different actors in the community.

In the precolonial towns, wells were placed in public and private spaces. The accessibility of water in public open spaces thanks to wells suggests that water was made available even to people who perhaps did not have a private well in their courtyard or at times when this well did not have water. Access to water likely enhanced the relevance of these urban open spaces as places where people met for conversation and social exchange.

It also raises the alluring question as to what extent access to well water might have been a factor in deciding on the placement of residential buildings. While mosques on Swahili sites nearly always have an associated well, the same cannot be stated for houses. In the so-called house blocks, for example, which represent a setting where multiple stone houses preserved in a dense cluster and had shared walls, there were pronounced differences between individual towns. At Gede, there are only two wells that may be associated with the stone house block on site, while at Jumba la Mtwana, each house in the block has its own well in the courtyard (see also **Figure 3**). However, even at Jumba with its high density of wells, there are stone houses which clearly did not have a well within their layout or in immediate vicinity. This question can hardly be resolved until there are more data and analyses focused on the placement of wells on a wider range of Swahili sites.

The question of site abandonment also deserves some reconsideration. There is no conclusive evidence that would support the theory that salinization of wells caused the abandonment of settlements or prevented their growth in the precolonial era as it has been initially argued for virtually all sites in the region, Gede, Kilepwa, and Jumba la Mtwana (Kirkman 1952; Kirkman 1954; Sassoon 1980). As present-day hydrogeological studies confirm, environmental conditions on the coast did not change significantly over time, while the means and intensity of their exploitation changed very markedly, especially in urban areas (Edmunds 2012). The much-repeated assumption that the abandonment of settlements was caused by salinization alone, is actually not very likely. It is a widely agreed public knowledge in the two case study regions today that water may still be available if a new well is dug a few metres to the side of an old exhausted well, where water management is practiced on a communal basis. This also suggests that salinization of wells rarely affects large stretches of coastal land. On Swahili archaeological sites, no direct evidence has been recorded of an effort to dig wells that never yielded freshwater, although such attempts may be expected to have occurred before a town of several hectares would be abandoned for lack of water, but on the other hand there have been no studies designed to answer this question.

In terms of practical implementation of archaeological knowledge in the contemporary world, the key factor is the widely shared recognition that water resources on the coast are not managed well with modern technologies that aim at high-yield water abstraction or at building piping for bringing water to coastal towns from inland rivers and lakes (Braune and Xu 2010). Hydrogeological studies have verified that the traditional way of sourcing water from wells is not only more sustainable, but also more effective as deep boreholes with greater abstraction rates quickly and sometimes permanently deplete water resources of the coastal areas (Comte *et al.* 2016). Conversely, past water management strategies are still effective today in the context of small towns at least, as contemporary communities describe good experience with practices that are characterised by similar distribution and size of water features like those preserved on archaeological sites. It is changes to this system that may cause problems, exemplified e.g. by modern plumbing that in combination with boring correlates with water disappearing or failing to recharge in the system of shallow freshwater lenses.

Conclusions

The review of past and present knowledge helps to point out priorities for future archaeological studies. To date, important questions have been underrepresented in research on Swahili towns, which include a need for complementing archaeological datasets on water management as well as reformulating interpretations of the precolonial past. In terms of documentation, there is a lack of data, for example, on the width and depth of wells that could be used in comparative analyses. Studies focusing on wells and water-related features on various types and sizes of sites are needed, as well as on possible patterns in the placement of wells within each site layout. Ethnoarchaeological studies on the knowledge and practices associated with manual digging of wells would also immensely help interpreting the archaeological data.

In the studies of the Islamic world, comparative approaches have been employed relatively little, with predominant focus on the core Islamic regions in the Middle East. However, studies on Islamic societies in Africa may improve our understanding of global histories as well as expand knowledge on the solutions and adaptation mechanisms that were achieved in the Islamic world. Data from the East African coast represent valuable parallels for understanding regions, where freshwater availability is scarce or highly fluctuating, in Africa (Steyl and Dennis 2009) and beyond.

From a long-term perspective, however, water management histories are even more relevant for informing our current decision-making and helping us find solutions to pressing water-related issues and needs. In the case of the Swahili coast, the precolonial period significantly enhances our understanding of sustainable principles that were successful in the region for centuries and represent proven adaptation strategies at least in a small-town context, such as small-scale exploitation of resources through a system of wells or rainwater harvesting. In small to medium-sized towns, we need to find ways how to encourage and recover strategies that are no longer used to their full potential or they gradually disappear. It is especially rainwater harvesting as an important part of precolonial water management that has mostly gone out of use in some towns, placing higher demands on water brought with pipes or causing water scarcity and social tension especially during dry seasons. In larger towns this may be more problematic, but a promising course of action would be to explore ways in which the old and new systems and technologies could work together.

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Chapter 11.
Building Landscapes with Water in al-Andalus. Historical Irrigation Systems as Cultural Heritage and Examples of Sustainability and Resilience

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Introduction. Historical irrigation systems. Cultural legacy of al-Andalus

There is an abundance of literature on the importance of water in al-Andalus in general, and on agriculture and irrigation systems in particular. It is undoubtedly a fundamental legacy, which is still very much alive in many areas of the Iberian Peninsula, particularly in the eastern part of Spain, including the Balearic Islands. Although we do not have reliable data on the number of historical irrigation systems that have survived to the present day, nor how many of them are from the Islamic period, it is safe to say that there are several thousand systems, with hundreds of thousands of hectares of irrigated land, which the legacy of al-Andalus left behind after the feudal conquest and colonisation, and even after the definitive expulsion of the Moorish population in 1609. It is precisely this historical evolution from the processes of Christian conquest and colonisation that will mainly determine the possibility of the conservation of irrigated areas, with a clear difference between the crowns of Aragon and Castile, as well as Portugal, but also with an evolution in the occupation policies throughout the prolonged process until the disappearance of al-Andalus. There are also documented processes of construction of new feudal irrigation systems within the Crown of Aragon, imitating the Andalusian irrigation systems. This does not seem to be the case in Castile where they were preserved, mainly in the kingdom of Murcia and the old Nasrid kingdom of Granada. In recent years we have also been documenting historical irrigation systems of medieval origin in marginal mountain areas in Cáceres, Ávila, Segovia and Albacete (**Figure 1**). They are almost certainly of Andalusian origin, but at the moment there are a lack of studies to corroborate this.

A second moment of aggression and disappearance of these systems is now taking place, as a result of the processes of agricultural industrialisation and global change. This was first reflected in an intense migratory movement from rural areas to the main Spanish cities, and to the centre of Europe in the 60s and 70s of the 20th century, a movement that has not yet ended, therefore aggravating the problems of depopulation in rural areas. Added to this migration is a strong industrialisation and technification which, in the case of irrigation, is even more recent, since the mid-1990s, and is being strongly supported by public policies and investments for the sake of a misunderstood efficiency with brutal impacts at all levels.

Most of these historical irrigation systems are certainly at least a thousand years old, as they are the result of the social, cultural and economic transformation processes that took place after the Islamic conquest in 711. They are also the result of co-evolutionary processes, of the mutual adaptation of humans to the environment, but also of the adaptation of the environment to new conditions introduced artificially as part of the productive strategies of past societies. They are the basis of socio-ecological systems that have generated landscapes with a wealth of cultural, social, productive and environmental values. They have also proven to be highly sustainable and resilient over the centuries, as well as highly productive. They have traditionally yielded two uninterrupted harvests per year and, where the climate permits, up to three harvests per year. And this has been done not only without depleting resources (not only water), but sometimes also by increasing them, as in the case of fertile soils.

They are, as we have said, an important cultural heritage, both tangible and intangible, which, in fact, has been recognised in December 2023 as Intangible Heritage by UNESCO. They stand out for the cultural landscapes they have created and for their technical sophistication but, above all else, for their social complexity. In fact, these systems are the result of an enormous collective effort carried out by the peasant communities. This effort does not only involve opening up kilometres of irrigation ditches on the ground, but also calculating slopes or building embankments and galleries where necessary. It also involves modifying the soil, in some

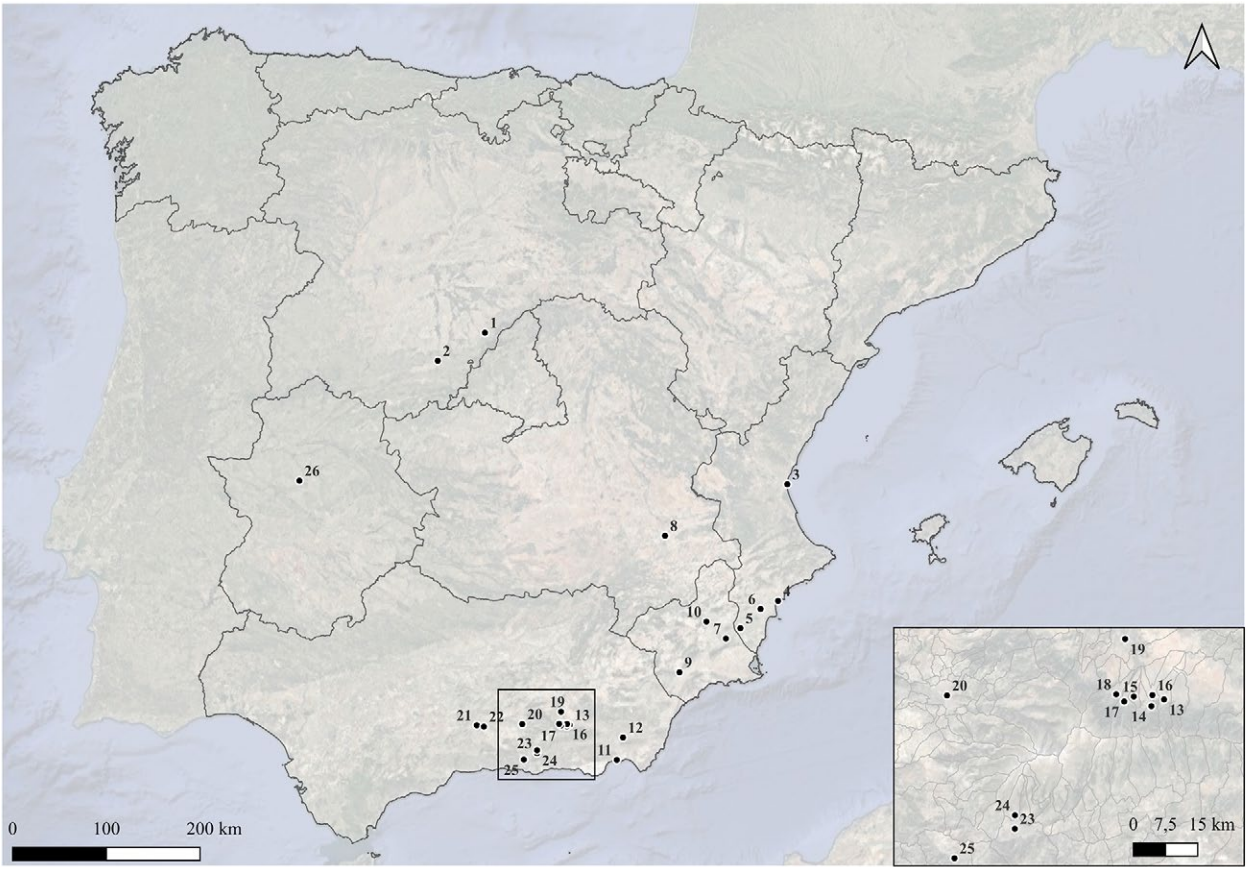

Figure 1. Places named in the text: Segovia (1), Ávila (2), Valencia (3), Alicante (4), Orihuela (5), Elche (6), Murcia (7), Albacete (8), Lorca (9), Ricote (Murcia) (10), Almería (11), Tabernas (Almería) (12), Ferreira (Granada) (13), Aldeire (Granada) (14), La Calahorra (Granada) (16), Alquife (Granada) (15), Lanteira (Granada) (17), Jérez del Marquesado (Granada) (18), Guadix (Granada) (19), Granada (20), Loja (Granada) (21), Salar (Granada) (22), Órgiva (Granada) (23), Cáñar (Granada) (24), Los Guájares (Granada) (25), Cáceres (26).

cases radically, as in the case of the cultivation terraces. Here, in addition, it is necessary to build retaining walls by mobilising an enormous amount of earth, organic matter and stone. But above all, it was necessary to agree on the design of the system, both in the layout of the irrigation ditches and the irrigable area and in the distribution of water and the establishment of rights. This must have been, without doubt, the most complicated part.

In general terms, we can say that an irrigation system is a complex human construction that consists of capturing water from a point, conducting it through a main channel or irrigation ditch and distributing it through other smaller channels that distribute it to its destination, which are the fields and vegetable gardens.

And while it is vital to calculate where to take the water, to correctly establish the optimal slope to avoid soil erosion, or to raise the cultivation terraces properly, what is really difficult is to agree on how to share and distribute the water; namely, to establish how much is allocated to each plot and at what time. In order to regulate all these issues, systems of communal governance were created, represented today in the irrigators communities (*Comunidades de Regantes*), the ultimate bodies in charge of managing the system and the water and agreeing on the rights and obligations of each commoner to enjoy the system and, in turn, to keep it clean and functional at all times.

Thus, it can be said that all historical irrigation systems are composed of two levels or two units:

Firstly, the **technological unit**, which includes all the infrastructure necessary for the collection, transportation, regulation and distribution of water. Normally a system has only one water collection point, either surface (by means of a dam) or underground (with drainage galleries, wells or from a spring). From there, it is channelled through a main irrigation channel, usually called the mother, from which smaller branches, which in turn can be subdivided into smaller ones, will branch off. In the systems we have studied so far, we have documented up to five levels in the hierarchy of these secondary ditches or branches. For this purpose, there may be construction site dividers. Sometimes there are also communal regulation basins. In addition, this technological unit also includes all the infrastructure that use water power, such as mills, fulling mills or blacksmiths, which use water but do not consume it.

Superimposed on this technological unit is a **social unit**, which is the community in charge of water governance and the catchment and distribution system. This community is composed of all landowners who have the right to use water for irrigation. Water is not a right of the landowner, but of the land, and normally cannot be separated from the land since it does not belong to the farmer. When this does happen, this dysfunction of the communal system can eventually erode it. The community is an institution governed by a system of governance, in which the rights and obligations of each member are established. This includes water rights, established by turns or batches according to the irrigable area and water available when the system was originally designed or through historical changes. The metering and allocation system is essential to ensure access to water and compliance by everyone. In addition, obligations are set out to keep the infrastructure operational, both for those parts that are communal and those that are proprietary but affect more commoners. This is also where an important part of local ecological knowledge is put into practice in relation to water availability forecasting, water regulation, adaptation to scarcity and community-dependent peasant livelihood mechanisms. This knowledge and operations include measuring distances, land areas, water flows and volumes, and the time for irrigation.

Decision-making is done in the community assembly, which is made up of all the commoners, i.e. all landowners with the right to use the water. The assembly establishes the regulations and by-laws governing the community and elects the board and its officers, who are in charge of the day-to-day management. This usually includes an *acequiero* or water guard (or several, depending on the size of the system), who is in charge of watching over the channel and even distributing water when necessary.

The assembly also appoints the court for the settlement of internal disputes. All communities are endowed with courts, which have legal validity and whose decisions and rulings are binding. Conflict is an inherent part of irrigation systems, because water management is extremely complex, and the livelihood of the farmer group depends on it. But the governance system allows for its resolution as one of the basic mechanisms for the functioning of the community. Another of these mechanisms is social surveillance and cooperation, which often work in a complementary way. Thus, for the maintenance of infrastructures, everyone had to collaborate by working on the raising of dams or the cleaning of irrigation ditches. If you could not go directly you had to send someone to replace you, and if they could not go either, you had to pay for the community to hire someone.

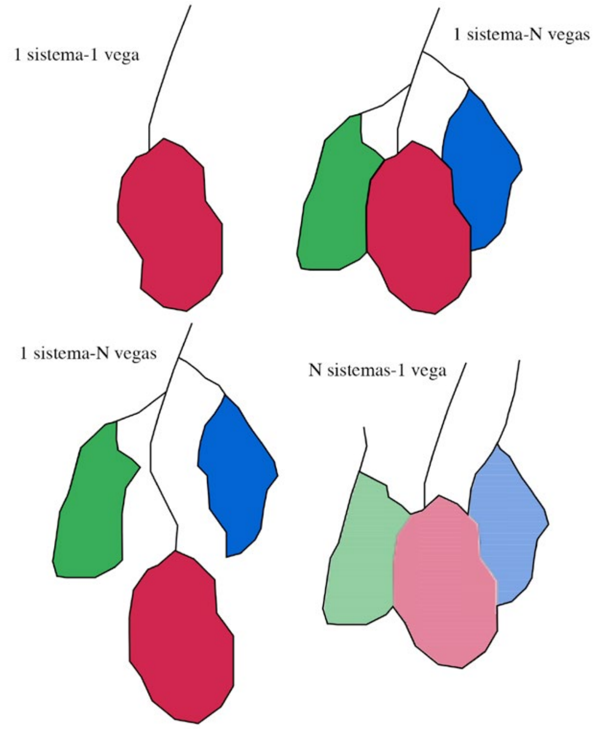

Figure 2. Diagram of the relationship between system (technological unit) and *vega-huerta* (social unit)

There is not always a correspondence between an irrigation system (technical unit) and a community that manages it (social unit) (**Figure 2**). In many cases they coincide and there is a 1:1 ratio, but in other cases we find variations that are particularly interesting because they tell us not only about the implantation and construction of the cultivation areas, but also about the historical evolution of the territory and the settlement. Thus, sometimes the same system is managed by several communities, usually in different villages (1:N ratio). It may be the case that there is physical continuity between infrastructure and fields, but that administratively there is a change, and several communities share a catchment and a mother irrigation channel. On other occasions there may be a physical separation with an intermediate space that is not irrigated or that only has occasional irrigation rights with surplus water. But we have also documented communities that manage more than one irrigation system on their own, with several catchments and several irrigation ditches (N:1 ratio). In these cases, the infrastructure and water rights are generally kept separate, although the community that manages them is the same. Based on these variations and on the water rights, we can not only interpret part of the original processes of construction and design, but also those of historical evolution, with processes of aggregation or segregation over time.

However, despite the importance of water and irrigation in al-Andalus and an abundant literature on the subject, we still know relatively little about its real impact, its social significance and its functioning mechanisms. There are, in fact, many debates still open and many other questions to be raised. It is undoubtedly a complex issue. Firstly, because it is part of the productive strategies and the basis of social relations in an area, the rural one, which, despite being the majority, generates much less documentary information. Secondly, because they are community and peasant institutions, as well as management practices, whose material remains are much more difficult to document and interpret in archaeological and historical terms, they therefore often appear to be unalterable and lacking in evolutionary processes. Thirdly, because they are not a manifestation of power, which has always attracted more research and, of course, heritage recognition and the need for protection in comparison to peasant constructions and forms of expression.

Cultural Landscapes and Archaeology

The study of landscape from a cultural or heritage perspective has aroused special interest in our society in recent decades. Partly because of the creation of a greater ecological awareness of our natural environment, but also because of the need to know and conserve cultural landscapes that are under attack and which, in many cases, are disappearing at an accelerated rate as a result of the processes of Global Change.

The cultural landscape is a complex reality, made up of natural and cultural, tangible and intangible components, the combination of which shapes its identifying character. According to the UNESCO *World Heritage Convention*, different types of cultural landscapes can be distinguished, which have led to their official classification (PNPC). Within this classification, special attention has been given to rural landscapes, which make up by far the largest part of the world's territory and which are the ones that are fundamentally attacked by the development of other areas such as urban and industrial (including infrastructure and the process of agricultural industrialisation itself). These are, moreover, the main object of our study.

The introduction of agriculture as a productive strategy converts the natural landscape into a rural landscape. In this sense, it can be said that agricultural activity involves a process of artificialisation or culturalization of nature. It is, in fact, in the areas of 'ancient agricultural and livestock culture' where the humanisation of the landscape is most profound. 'The history of agriculture and human nutrition is one of the best clues for the interpretation of changes in landscapes with prolonged anthropic influence' (González Bernáldez 1981: 145-147).

Archaeological research can never disregard the study of the environment in which human beings have lived. Implicit in the process of production and reproduction is a relationship with nature, from which raw materials and energy are extracted. The environment undoubtedly conditions the way in which societies develop, but they also adapt the environment, sometimes radically transforming it, creating strongly humanised landscapes and new ecosystems dependent on the external energy input introduced by the hand of man. K Butzer (1982) introduced the concept of ecosystems in Archaeology, being understood as a set of living beings that relate to the physical environment in a given area. Applied to the 'human ecosystem', this concept highlights the interdependence between environmental and cultural variables.

Indeed, a more elaborate theory and a more complex working methodology have recently been introduced into the archaeological debate, which attempts to establish a direct relationship between the places of settlement, the working spaces and the territory. Archaeology has undergone an important evolution in recent years, not only because of the appearance and development of new techniques, but also because of epistemological changes that have gone hand in hand with the development of an increasingly complex conception of our discipline and our object of study. Indeed, information technologies, graphic documentation techniques, dating or archaeometric and biological analysis techniques are increasingly sophisticated and precise, and capable of providing and managing a greater number of new types of data and information. This has meant the ability to develop new questions and possibilities for interpretation at many levels, from metal production technologies to the provenance of human populations. It has also allowed us to change our conception of the archaeological deposit and to document it for the first time not only in three-dimensional, but even four-dimensional form. It has also made it possible to change our scale of work in real time, truly integrating spatial data at the territorial level.

But as we say, these changes have run in parallel to the emergence of new questions and the development of existing questions about our own practice as scientists. This epistemological development, which is currently in full swing, is not only the result of the influence of technological advances, but also of a profound theoretical reflection on our object of study, methodology and the different approaches to interpretation. The eruption of the post-processualist school of thought has led to the emergence not only of the local, the particular or the relative, but also of the subjective. The dialectic with respect to the 'scientistic' visions of the processualist schools of thought or the new social and environmental challenges we face have led to numerous debates on the role that archaeology should play in the current and future global context, on its usefulness and forms of socialisation, on conservation and on the scope of the concept of material culture.

It is within this context that we must situate the emergence and, above all, the recent development of Landscape Archaeology at an international level. Landscape began to be the subject of study in Archaeology with the publication of Bradford's *Ancient Landscapes* (1957). It was not until 1974 that Aston and Rowley used the term "palimpsest" to refer to landscapes, an expression that would later be disseminated by Chevallier (1976) and which became so popular in History and Medieval Archaeology from the 1980s onwards. Since then we can find more and more references to it in our discipline, although on many occasions the conception has been different. We will not now go into the question of its different meanings and interpretations, but it is necessary to consider the problems of definition and approach in order to carry out a critical approach to the development of Landscape Archaeology (Orejas Saco del Valle 1991).

It is true, moreover, that the study of landscape brings together numerous scientific disciplines (from which Archaeology has borrowed the concept itself), not only from the humanities and social sciences, but also from the natural sciences. This adds a further element of complexity, not only when it comes to understanding what we mean when we talk about landscape, but also when it comes to analysing it from an archaeological point of view. Furthermore, we must bear in mind that landscape has become a key term (sometimes totemic) for administrations, managers, social movements, for many economic interests or for citizens themselves, whether it is understood as a place of identity or as a space for leisure.

Despite the problems of a lack of definition, the inclusion of landscapes as an object of protection, and their protection at the international level, both by UNESCO and the *European Landscape Convention* (2000), has gradually fixed the idea and scope of their definition. There has been a shift from a conception linked to perception and the senses (including aesthetics) to an idea of landscape as a socio-ecosystem, the result of a co-evolutionary process, developed from the fields of Anthropology and Ethnoecology (González Bernáldez 1981; Tello 1999). In this sense, landscape also has a more material (less subjective) expression, as a result of the relationship processes between humans and nature (which include metabolic processes, but also local ecological knowledge and practices). Often this conception is not even expressed in these terms, but simply in the study of productive processes, as in the case of Agrarian Archaeology.

As we have already said on other occasions (Martín Civantos 2006, 2008; Brogiolo 2007), the current landscape is the result of the accumulation of the remains of the various historical landscapes that have succeeded each other over time. It is, in short, a social landscape produced and, therefore, forms part of the material culture of the societies that created those ancient landscapes. Essential to its formation are, among other things, the interaction between humans and nature, but also the way in which a particular social formation expresses itself in space (García de Cortázar 2004).

The epistemological and interpretative differences are rooted in different academic traditions, which in turn draw from or are related to different scientific disciplines. The Anglo-Saxon and French traditions are mentioned mainly, which have had a decisive influence on the Spanish panorama (González-Villaescusa 2006). However, it is not always easy to keep track of the schools and different trends, both theoretical and methodological, especially in an area such as landscape, which is sometimes ill-defined and even slippery.

The French influence is more complex, because through the *Annales* school it does not only come from Archaeology. The French academic presence and influence is very evident in more than one generation of researchers, mainly through Medieval History, from which Spanish Medieval Archaeology emerges. This important tradition is visible in the Andalusi studies field (Bazzana, 1986, 1993, 1994; Bazzana, Guichard, Cressier 1988; Bertrand, Cressier 1985; Cressier 1984, 1999; Cressier *et al.* 1989, 1992), including Hydraulic Archaeology and the study of irrigation systems developed by M. Barceló and his team (Barceló, 1988, 1989, 1992; Barceló, Kirchner, Navarro 1995; Kirchner, Navarro 1993; González-Villaescusa, Kirchner 1997). The beginning of studies on Andalusi irrigation from an archaeological perspective must be situated here, though they are fundamentally preceded by historiographical debates grounded in written sources.

The debate on irrigation in al-Andalus and the role of Archaeology

Much has been written and researched on this subject since the works of T. Glick (1970) and A. Watson (1974, 1983), not only in relation to al-Andalus, but to the Arab-Islamic world in general. In particular, the so-called 'Islamic Green Revolution' has generated significant literature from the Middle East and around the Mediterranean, although we believe that it has not really received sufficient attention given the significance and complexity of the initial proposal. The term and the proposal, in fact, have been criticised and questioned from various quarters in recent decades, including by A. Watson (2007). A recent critical review can be found in the publication of H. Kirchner *et al.* (2023). Indeed, irrigation was already known and intensively employed in Mesopotamia and throughout the Middle East long before the appearance and expansion of Islam; the process of plant expansion that Watson studies has been shown in many cases to be erroneous, more complex or later; the archaeological identification of plants has also called into question this interpretation and its correlation (or rather problems of correlation) with written documentation. However, despite some calls to open up or broaden the innovative elements of the 'Green Revolution' to include animals, growing conditions or tools and management, Archaeology has refined its methods but has remained primarily focused on the distribution of plants and crops (Kirchner et al. 2003: 3).

We will focus on the case of al-Andalus, although what we have argued could be applicable to other territories conquered by the Islamic world on which we have been able to work, such as Sicily (Martín Civantos et al. 2023). The interest, we can say, has centred on three fundamental axes: on the one hand, the subject of the plants brought by the new conquerors from distant areas of the East, from climates outside the Mediterranean; on the other, the technological innovations introduced from outside and/or developed in the peninsula and which have their maximum expression in the Andalusi school of Agronomy; lastly, and in our opinion the most interesting, that which studies the processes of peasant work through the construction of irrigation areas by the new settlers who arrived from 711 onwards, both Arabs and Berbers, and which has led to the development of what is known as Hydraulic Archaeology.

The first is mainly represented by A. Watson himself in his seminal work *Agricultural innovation in the Early Islamic World* (1983). In it, as in other works, he not only studies the spread of these new crops and the ways in which they spread, but also the elements that influenced their spread in the early Islamic period.

The second line, closely related to the question of new plants, is the study of the Andalusi agronomic school and the innovations developed or collected by this monumental scientific production that was especially protected and promoted by the Andalusi rulers from the Umayyad period onwards. The main representatives of this type of study are L. Bolens (1981) and E. García Sánchez (1990-2004). The latter is one of the visible heads of a larger group of researchers dedicated to the study of Agronomy and Botany, who approach the subject from the perspective of the Natural Sciences in the Andalusi world, also in relation to medicine and food. Other researchers such as J. Carabaza Bravo (1994) should be added to this group.

Finally, the study of irrigation systems as peasant work spaces has been addressed mainly by M. Barceló and his team, especially H. Kirchner and C. Navarro, but also since then by a wide range of researchers. Th. Glick (1997), and later the rest of the authors, associated the analysis of agrarian spaces with that of Andalusi society. In this sense, the impact of the work of P. Guichard (1995) on the oriental type of social structures in al-Andalus will be fundamental in understanding the relationship between the two. It was P. Guichard himself, together with A. Bazzana (1981), who highlighted the close relationship between irrigated agrarian spaces and the settlement structured in *alquerías* (villages) that were integrated into castral districts.

Since then the controversy between the Eastern or North African origin of irrigation techniques and forms of water distribution arose. As M. Barceló (1986, 1989) himself put it, the problem is not so much to determine the origins of certain techniques or irrigated spaces, but to study them in relation to the society that builds and uses them. In this sense, it will be the peasant communities organised by their kinship ties that will spread and consolidate the construction of irrigated spaces and the new plants associated with them.

As has been demonstrated, intensive irrigated agriculture is one of the main economic bases on which the development of al-Andalus as a society and as a political structure is based. Thus, to raise the question of the social significance of irrigation in the Andalusi world is to enter into the debate -today virtually at a standstill- on the Tributary-mercantile Mode of Production and the Islamic social formation (Amin 1976; Barceló 1984; Wickham 1985; Haldon 1998a, 1998b; Acién Almansa 1998; Manzano Moreno 1998, 2006; García Sanjuán 2006). By its nature, this activity necessarily had to condition the relationship work-means of production, the social relations of production and the relationship between the peasant communities and the Islamic state, i.e. the forms of extraction of the productive surplus.

Thus, to speak of the social significance of intensive irrigated agriculture in al-Andalus implies raising issues such as the relationship between irrigation and land ownership; between the distribution and control of water and the social structure; between the control of water and the organisation of peasant communities; between the control of water and territorial organisation; between intensive irrigated agriculture and taxation; between intensive irrigated agriculture and trade.

Obviously, we are not going to go into these questions now. We will simply state a few elements that seem to us to be of interest in order to further deepen our knowledge of these workspaces:

The **first problem** we face is **quantification**: what is the real size, in number of hectares, of irrigated agriculture in al-Andalus? We do not really know. Despite M. Barceló's proposal to draw up a "hydraulic map" using archaeological methodology, there is still a long way to go before such a map can be drawn up. The study by E. Sitges (2006) published in 2006 catalogued a total of 161 hydraulic systems in the ancient territory of al-Andalus, but despite this effort they were only a very small sample, referring mainly to the Balearic Islands. In the current province of Granada, for example, only a few systems have been studied in depth, such as the small system of Los Guájares (Barceló et al. 1987), those of Zenete (Martín Civantos 2007), on the north face of the Sierra Nevada or the land of Loja (Jiménez Puertas 2007), in the western part of the Vega of Granada, leaving practically everything to be studied. Even so, at MEMOLab UGR we have developed several research projects that have allowed us to map more than 4000km of irrigation ditches in the field. Since 2015 we have been carrying out extensive work to document the historical irrigation systems of the provinces of Granada and Almeria (https://regadiohistorico.es/). Just in these two territories we have registered more than 830 systems, managed by some 550 irrigators communities, representing some 200,000ha of irrigated land and more than 190,000 irrigators (landowners with the right to use water). Spatial calculation based on available

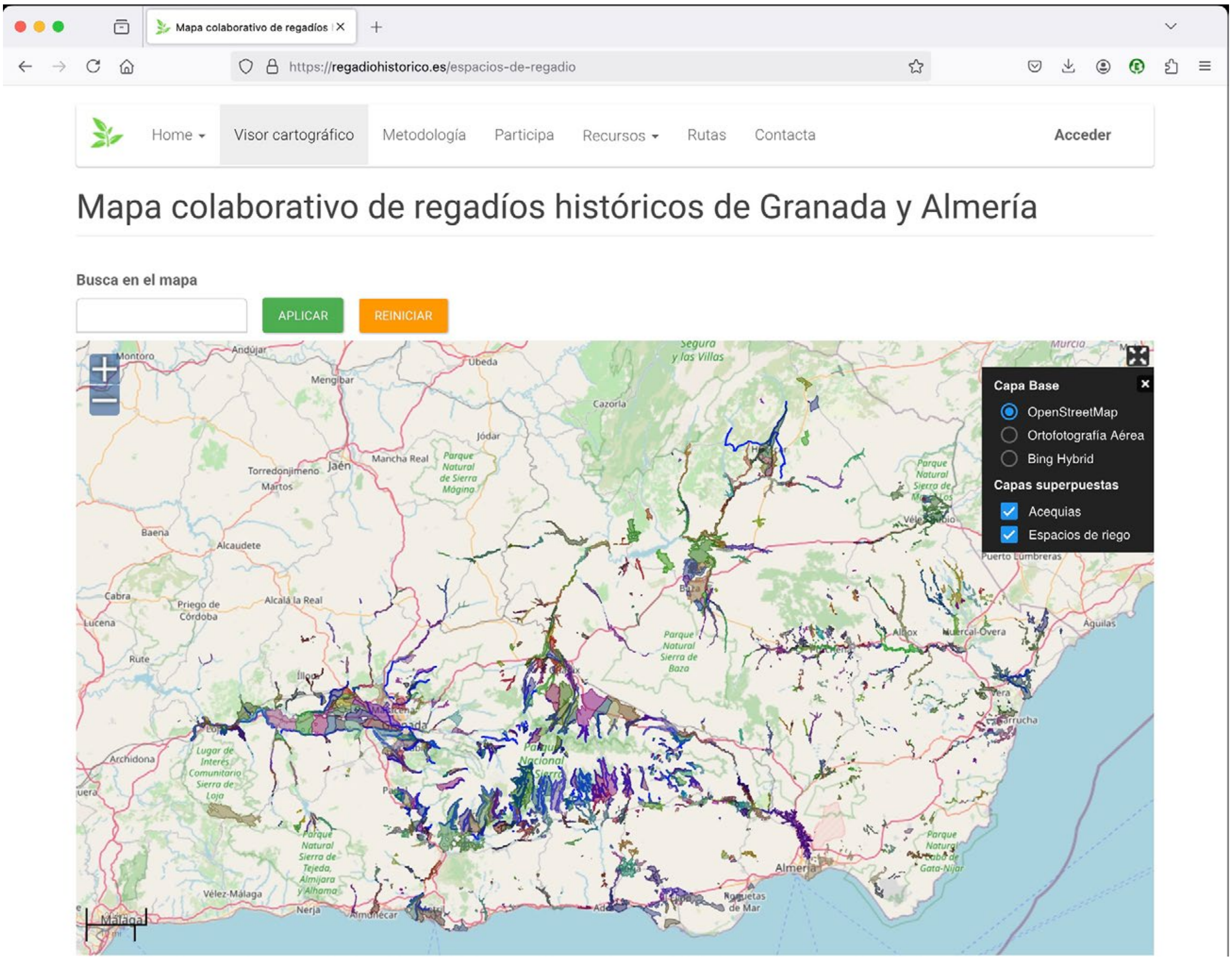

Figure 3. Cartographic viewer of the historical and traditional irrigation systems of Granada and Almeria (https://regadiohistorico.es/espacios-de-regadio)

field data allows us to say that these extensions would represent some 24,000km of irrigation channels. The vast majority of these systems, more than 95%, already existed in the Andalusi period and can be documented to at least after the Castilian conquest (**Figure 3**).

On the other hand, within these systems we find important differences in size which, although they do not mean that they are more or less complex, are significant from the point of view of production. A first attempt has already been made to classify these spaces according to their size, between macro-systems (larger than 100ha), meso-systems (smaller than 100ha) and micro-systems (smaller than 1ha) (Butzer *et al.* 1988). The proposal by E. Sitges (2006: 284) is very different and is based on the reality of the numerous case studies collected, of which only fourteen exceed 2ha of irrigated land, the largest is only 15ha and the average is 1.2ha. No doubt, these attempts at classifications are very outdated. If we compare these data with other rural areas such as those studied by us in Granada and Almería, where practically all of them exceed 200ha each, or with the extensive urban fertile plains (*vegas* or *huertas*) of Granada, Lorca, Murcia, Orihuela, Elche, Alicante or Valencia, the difference in productive capacity seems evident. In reality, despite the fact that historiography has traditionally emphasised the importance of irrigation as one of the productive bases of al-Andalus, there is an obvious contradiction between the sizes included in the proposed classifications and the reality of many irrigated areas. This does not mean, however, a disregard for the smaller systems, which in many cases, when added together, end up forming large irrigated areas and which were, moreover, fundamental for the subsistence of numerous families or for the development of a dispersed population that structured the territory.

The second problem is qualitative: What is the level of production achieved by this type of agriculture and what productivity did it achieve in relation to rainfed land? Although irrigated land represents a theoretically smaller area of land in quantitative terms, its productivity is much higher and, therefore, the resulting production is probably also higher. In reality, we do not know what the productive levels are that are achieved by these lands, which depend not only on the water input, but also on other factors such as crop intensification and management techniques and soil type. Generically, at least three objective variables could be considered: the amount of water available, the extension of land to be irrigated and the quality of the land (including its structure, depth, moisture retention capacity, etc.), although other aspects such as slope, humidity and temperature, sun exposure, etc. could also be considered. To these should be added other aspects that are more difficult to quantify, such as the skill and knowledge of the farmers in the management of techniques and crops; the type of plants and their adaptation to the environment; the organisational capacity and cohesion of the farming communities themselves; the nature and degree of external coercion; the role played by agriculture in the community's productive activities as a whole, etc.

An example is the case of occasionally irrigated land. These are lands that are irrigated sporadically when there is excess water, but which are not entitled to irrigation during the summer. They have been documented in the north face of the Sierra Nevada (Granada) (Martín Civantos 2007), but it is likely that they existed in many other places and that they have either left no documentary or material trace or, quite simply, have been transformed into intensive irrigation areas through a change in agricultural use that would basically consist of reducing the yield per surface area in exchange for increasing the cultivated area during the summer. This is possible, for example, by changing the type of crops grown or by giving up some of the annual crops. In the cases studied these are communal lands irrigated only in spring when water, in this case from mountain snowmelt, is more abundant. The cereals are then irrigated a few times to ensure an ever-scarce harvest on poor soils. But the presence of snow and mountainous areas was probably not necessary for this type of eventual irrigation to exist. Certainly, in spring there is surplus water (although it will always depend on rainfall and temperature), and with the same volume of water it would be possible to irrigate a larger area until the arrival of summer, when irrigated land is reduced to the most fertile part, where fruit trees are usually planted. This intensively irrigated area usually coincides with the private ownership of the land. On the other hand, irrigating fruit trees or vegetables is not the same as irrigating cereals, olives or vines. In fact, in the case of vineyards, a few irrigations per year are also possible, enough to guarantee production, but not that much to guarantee the production of sugars in the ripening process and to avoid the appearance of diseases due to excess humidity. For this reason, they are not usually located in excessively humid lowland or riverside areas, but on sunny plots, in many cases taking advantage of land with less developed or even stony soils.

Historical Irrigation Systems and Hydraulic Archaeology

Hydraulic Archaeology has had a scope of development restricted fundamentally to the territory of al-Andalus. Its objective is to reconstruct, over time, the processes of water use in irrigated agriculture, which creates systems of water collection and distribution dedicated fundamentally to intensive cultivation and which involve the transformation of landscapes into productive areas (Barceló 1989, 1995; Kirchner 1995; Kirchner, Navarro 1994). Their application must go beyond the merely technical or technological aspects, to insert their discourse within the social and economic dynamics of the territory in which they are framed, but also to understand the complex relationships established between human beings and the natural environment in the generation of agrarian-based socio-ecosystems.

At the core of Hydraulic Archaeology is the notion of the archaeological site as a remainder of human activity from any period or function. There is no doubt that, as T.F. Glick (1988) stated, irrigated spaces are artefacts. But, as we saw at the beginning of the text, to analyse them we must understand that they are primarily complex social constructions.

The study of the technological unit (the infrastructure) and the social unit (the community) from an archaeological perspective allows us to understand the original processes of design and construction of irrigation areas and their historical evolution. However, other perspectives from disciplines such as History, Anthropology, Agronomy, Hydrology and Hydrogeology must be added to the archaeological methodology in order to apply integrated and transdisciplinary approaches. These approaches must go beyond the merely descriptive aspects of catchment and transport systems to understand water governance, local ecological knowledge, productive strategies and adaptive processes and the relationship with the natural environment as part of history.

M. Barceló and H. Kirchner have already written about the original design of irrigation systems. Subsequently, exhaustive case studies have been carried out with the aim of searching for the original spaces and original designs of some systems based mainly on the morphology of the plots, as in Valle de Ricote (Murcia) (Puy 2013), Torrox (Málaga) (Retamero 2006) or the Huerta de Valencia (Esquilache 2018). It is not the purpose of this paper to critique these studies, but we believe that they deserve a global reflection on the capacity of peasant communities to design and build cultivation spaces, their size and peasant strategies (and therefore productive capacity, subsistence and autonomy, productive surplus or the relationship with land ownership) and the real possibilities of subsequent expansion and its consequences. Once again, size appears as one of the central issues, to which, as we said earlier, we must add that of productivity. This question is central, since irrigation is, according to the general consensus in historiography, one of the main bases of the economy and development of al-Andalus, of the autonomy of peasant groups (structured by kinship or neighbourhood ties) and one of the main bases of Andalusi social formation.

Moreover, as we said at the beginning of this paper, based on the relationship between the technological and social unit, its variations and the fixing of water rights, we can not only interpret part of the original contexts of construction and design of irrigated areas, but also the historical evolution linked to the evolution of settlement and territorial organisation, with processes of segregation or aggregation over time. Of the former, the cases of Aldeire-La Calahorra and Lanteira-Alquife, all on the north face of the Sierra Nevada (Granada), stand out by way of example. From Aldeire the territory of a new village (*alquería*) was segregated in the 10th century with the construction of a castle by the Umayyads, La Calahorra, which was given a part of the intensively irrigated lands (*vega*) and occasionally irrigated lands (*campo*), but not of the headwaters of the basin where the waters come from. The same situation can be found very close by, between Lanteira and Alquife. The second locality was created in the 11th century, in the Taifa period, with the segregation of part of Lanteira's land, including its intensive and occasional irrigation area, but reserving the upper part of the basin and the control of the source of the water (Martin Civantos 2007). The cases of aggregations seem to be more numerous and would respond to a general dynamic of population and settlement concentration, especially from the 12th century onwards, within the villages, with the abandonment of dispersed districts and the development of some localities, and the growth of the towns. This led to a process of absorption of districts, including irrigated lands and water rights, which nevertheless remained, as far as we have been able to document, unaltered. This will be the case of Jérez del Marquesado, also on the north face of the Sierra Nevada (Granada), which will end up absorbing five old villages from the 12th to the 14th century (Alcázar, Tuyina, Nush, Mecina and Bartillana), with their respective five irrigation systems, forming a new and larger locality (Martín Civantos 2007) (**Figure 4**). But it can also be seen in the evolution followed by the city of Granada or the city of Guadix itself, which will gradually expand their boundaries over those of other nearby ancient villages, which will end up becoming neighbourhoods or farmhouses (*cortijadas*) or simply disappearing. This process, however, is even less well known.

The second question that arises, and surely one of the most important and difficult to resolve, is that of the dating of the construction of historical irrigation systems. The fact that they are mostly peasant constructions, made with local materials that are constantly renewed as part of the process of maintenance and communal governance, makes it

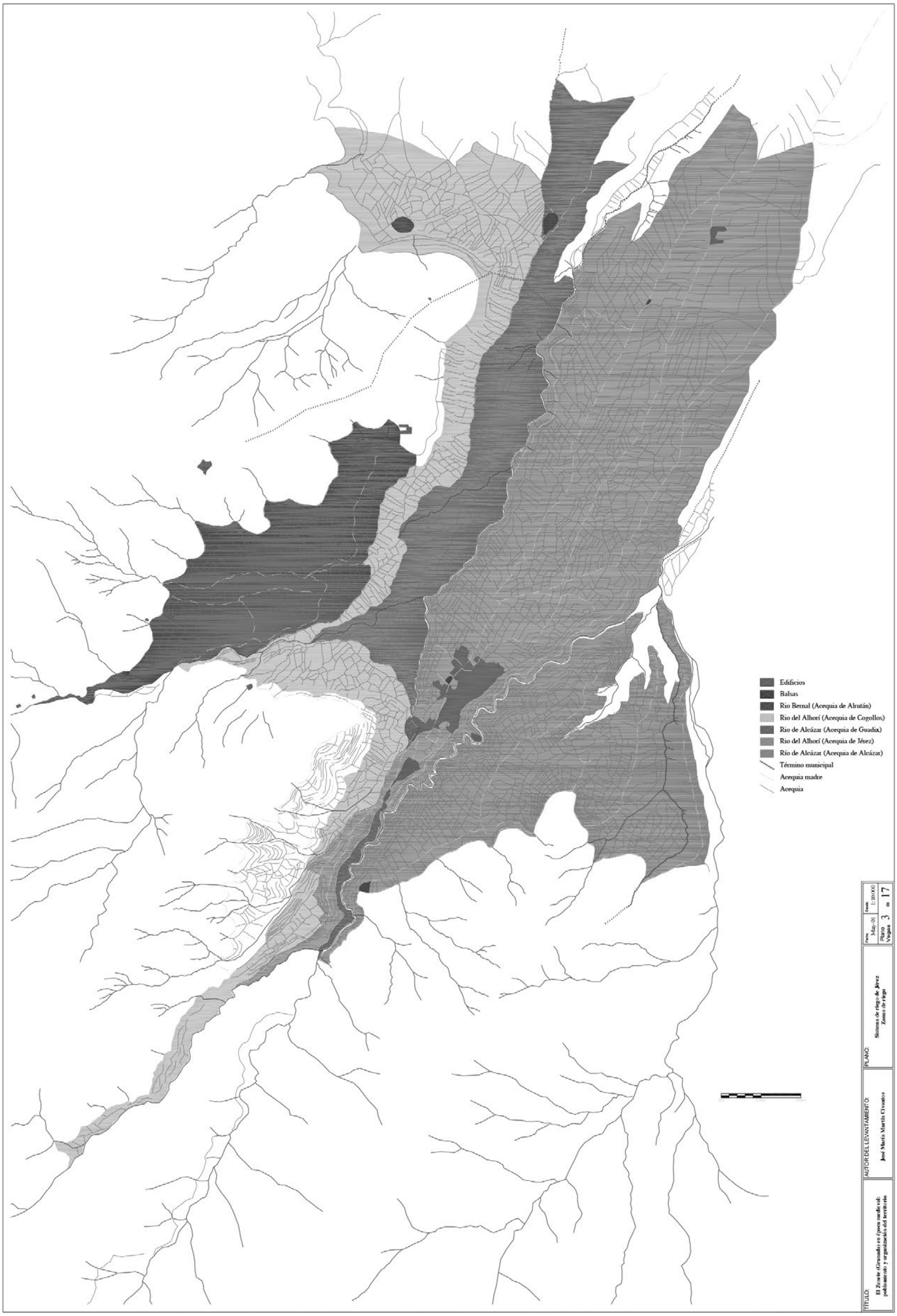

Figure 4. Irrigation systems and *vegas* in Jérez del Marquesado (Granada) (Martín Civantos 2007).

extremely complex and delicate to attribute an absolute chronology to the construction using the usual methods and techniques in Archaeology. Obviously, there are no documentary references to these foundations, and, in fact, there are very few subsequent written records, which are usually limited to distribution documents or water disputes. But neither is it possible in most cases to establish stratigraphic sequences or to obtain dates by C14 or other more current techniques such as OSL due to the renewal processes themselves or to the dynamics of soils that are in intensive production. In some cases, sealed contexts can be located under the cultivation terraces that allow us to establish *post quem* chronologies that can even be precise. This is the case of the interesting study carried out in Ricote by A. Puy (2013), or in some of those that we have been able to study in Granada, still unpublished, of settlements immediately prior to the construction of irrigated cultivation terraces (Órgiva, Ferreira and Salar).

But archaeological research on historical irrigation systems should not stop at these spatial and material aspects related above all to the infrastructure for the collection and transport of water or the morphology of the plots. As we have insisted, irrigation is fundamentally a social issue, and to really understand these productive spaces from an integrated (and transdisciplinary) perspective, it is necessary to study the communal governance systems, the water rights fixing and the social distribution of water. These mechanisms and practices are even more unfamiliar to research, not only because they are based on oral tradition and customary law, but also because they are particularly complex, and sometimes even cryptic. It is a matter of measuring water flows and/or volumes, land areas and time, all at the same time. Each plot of land entitled to irrigation is usually allocated a certain amount of water (sometimes a certain volume of water). However, this time does not necessarily correspond to a fixed amount but will depend on the available water flow. Moreover, even if the time entitlement does not change, it may be reduced proportionally in drought years. In some systems, irrigation is carried out in topographical order, in a batch (*tanda*), which is the time it takes to irrigate all the fields entitled to irrigation and then repeat the cycle. In other systems, shifts are established where the times are controlled in a more specific way (*turno*). There are also systems, mainly those with sufficient and regular flow, in which the water is divided by secondary branches by half, a third, a quarter or in any other proportion. There are communities that share the water from the same catchment or from the same resource (a river or a spring), and they also establish shifts between them according to the rights established at the time. There are also different ways of measuring water flow or volume, as well as land areas. We do not know whether the differences in the ways of organising the social distribution of water are due to local adaptations and evolutions or whether, as has been proposed, they are due to the different origins of the Arab populations settled in al-Andalus or even of North African origin, of which we know very little.

Nor do we know to what extent within the intensively irrigated areas there were also lands of different qualities with differentiated crops, such as vineyards or fruit trees. Furthermore, as we have pointed out, there are lands that can only be irrigated when there is water surplus, without having the right to use water during the summer. In the Andalusi period they must have been, in general, communal lands. To this we would have to add the use of torrential runoff waters in the driest areas by means of techniques called *boqueras* and *ribazos*. These practices allowed the retention and infiltration of the water floods, giving the soil enough moisture to be able to grow at least one cereal crop (**Figures 5 and 6**).

All these elements lead us to talk about another fundamental element, which is also linked to productivity and management. This is local ecological knowledge and practices, not only with regard to water (in the form of snow or liquid, surface or underground), plants, soils and animals, but also with regard to the sustainability of the system and its resilience. This knowledge and practices are, in turn, related to the

Figure 5. Irrigation area in Terque (Almería)

Figure 6. *Boqueras* system already abandoned in Tabernas (Almería) (B. Ramos Rodríguez)

conservation of resources, not only water itself, but also soil and its fertility (management, anthropogenic processes, terracing...) or genetic resources. But it is also related to the ecosystem services provided by historical irrigation (*Arguments*). We highlight water regulation services, which include the practices of water sowing and harvesting, recharging aquifers and springs artificially, generating irrigation returns and slowing the outflow of water from river basins. These practices are sometimes intentional, as in the case of the 'careos' of Sierra Nevada (Granada-Almería), that we have been able to study and document together with hydrogeologists and hydrologists who have demonstrated their efficiency in recharging aquifers in a hard rock impermeable context and in increasing water resources (Martos Rosillo *et al.* 2020; Jódar et al. 2022; Martín Civantos et al. 2022, 2023). In other cases, they are a consequence of other practices, such as winter irrigation, the previously mentioned *boqueras* and *ribazos* to take advantage of torrential rains or the water returns from surface irrigation.

All these are the different elements and processes that intervene in irrigated productive spaces and that were set in motion after the Islamic conquest of the Iberian Peninsula at the beginning of the 8th century. We know very little about most of them. In many cases these are topics that have not been raised until now. Today we know that they form part of enormously complex socio-ecosystems, which generate many cultural, social, agronomic and environmental values and produce numerous ecosystem services.

Conclusions - Historic irrigation systems: from the risk of disappearance to their future projection as tools to face the challenges of Global Change and the environmental crisis.

There is a growing body of evidence to support such systems as Nature based Solutions (NbS), ecological corridors, green and blue infrastructure, Integrated Water Management Systems (IWMS) and climate change adaptation tools (**Figure 7**). As already mentioned, over the last thousand years they have proven to be highly sustainable and resilient, as well as productive. They have generated cultural landscapes of great value. They are examples of socio-ecosystems in which co-evolutionary processes have generated

Figure 7. Acequia Real (Cástaras, Granada) (A. Bañuelos)

balances between humans and nature. They are also examples of participatory governance (*Arguments*).

And yet, despite all these arguments and the increasingly abundant scientific evidence of their usefulness, they are currently in serious danger of disappearing. As we said below, for decades they have been subjected to a double process that seems to condemn them to disappearance: firstly, emigration and depopulation of the rural world and the crisis of agricultural activity, which goes hand in hand with global cultural, social and economic changes that have gradually pushed aside the ways of life and expression of the countryside. On the other hand, in recent decades there has also been a strong process of agrarian intensification and industrialisation, which is more evident precisely in the case of irrigation towards a global and extremely competitive production model that also has enormous impacts on the natural environment, natural resources, landscapes and the local communities and farmers themselves. There is currently enormous pressure on irrigators communities to carry out irrigation technification projects, wrongly called 'modernisation'. All policies and public investment are geared towards these processes of destruction and replacement of traditional irrigation systems, without even considering what we are losing with these radical changes. And everything is done, in the field of water policies, for the sake of a misunderstood efficiency, conceived only from a narrow and outdated productivist and extractivist perspective. The basic premise is that of saving water through the implementation of highly technical pressurised and localised irrigation systems. Theoretically, savings are usually around 30%. However, it has been widely demonstrated that these policies have resulted in a truly unsustainable increase in water consumption as part of what is known as the Jevons paradox (Lecina et al. 2009; Perry *et al.* 2017; Grafton et al. 2018). The effects are, as we say, devastating, with an accelerated depletion of resources that accelerate the effects of Climate Change, as well as truly negative social, cultural and environmental consequences.

However, at the MEMOLab of the University of Granada we have been working for ten years now with irrigator communities to defend historical irrigation systems and their water rights, not only researching and arguing from a scientific point of view but also proposing real alternatives. Our proposal is based on a conception of water efficiency based on multifunctionality and the production of ecosystem services, which are nowadays fundamental to face the challenges of the environmental crisis. To this end, we have been restoring more than 100km of irrigation channels since 2014, working with the communities themselves and with thousands of volunteers who have attended the planned activities. The restoration of irrigation ditches is a social intervention tool that allows us to work in a different way with the communities (**Figure 8**). Firstly, by giving them recognition and visibility, empowering them and trying to reactivate them to improve their governance systems and recover local ecological knowledge and sustainable management practices, incorporating nature conservation and ecosystem services as a fundamental part of their activity. In this sense, the restoration of irrigation channels can be said to be a provocation, both for the communities and for the institutions responsible for hydraulic, agrarian, cultural heritage and territorial policies.

From there, we have been proposing other social innovation tools that are always based on multifunctionality and have a positive return, both material and symbolic, for the communities. The first has been the agreements on payment for services, signed initially between the community and its local council, but with the idea that they are not only replicable but also scalable. Within these services provided by the irrigators communities, we have also included the creation of cultural trails along the irrigation channels as a resource made available to the municipality for use and exploitation. The second has been the Land Stewardship contracts between the University itself, or other local entities, and

Figure 8. Acequia de Barjas restoration in 2014 (Cáñar, Granada)

the irrigators communities, to support the nature conservation work they carry out. The third has been the development of participatory management plans by the irrigators communities, which consider not only the practical aspects and infrastructures, but also the ecosystem services themselves and the values they generate. Fourthly, we have proposed the implementation of river contracts at sub-watershed scale, to agree and promote collaboration between water users to improve planning and public policies. Fifthly, the promotion of productive alternatives based mainly on sustainability criteria, including support for local and agro-ecological production, the recovery of local varieties or the development of agroforestry projects for use as structural wood (https://revierte.es/) (**Figure 9**). Lastly, we have enabled and boosted associations between irrigators communities, so that they can collaborate and work together to defend their historical rights, their work and governance systems, to give visibility to these values, knowledge and work, and to be interlocutors with the public administration, pushing for changes in public policies in line with a more integrated and sustainable vision of agricultural activity and water policies.

Figure 9. Acequia del Jaufí (Benamaurel, Granada)

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Chapter 12.
Water Management and Irrigation Systems in Islamic Sicily and Beyond

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Introduction

After initial economic raids by Islamic forces from North Africa on the Sicilian coasts, the island was gradually conquered by the Aghlabid army during a protracted conflict lasting from 827 to 902 CE (all dates are CE unless otherwise stated) (Granara 2019). Aghlabid emirs governed Sicily through appointed officials based in Palermo until the 10th century when the Fatimids gained control of both North Africa and Sicily. Between the 9th and 11th centuries, Sicily underwent significant cultural, religious, and economic integration into the *dār al-Islām*. This transformative period saw the gradual Arabization and Islamization of society, while elements of the island's indigenous Greek Christian and Jewish traditions persisted (Davis-Secord 2020). Tenth-century Arab geographers, such as al-Muqaddasī (al-Muqaddas 1994) and Ibn Ḥawqal (Ibn Hawqal 1964), described Sicily — particularly its capital Palermo, the ancient *Panormus* later known in the Islamic period as *Balarm* or *Madīnat Ṣiqilliya* — as an Islamicate city, with its mosques, Islamic schools, and agricultural practices, as well as its social customs, which aligned Sicily under Islamic rule with other regions of the *dār al-Islām* (Bagnera 2013). Despite these vibrant descriptions of Islamic Palermo, the city's current state lacks the monumental characteristics it once possessed. Ongoing construction activities have precluded the preservation of standing buildings from the Islamic era. Despite this, in recent years archaeological research on Islamic Sicily has greatly intensified (Nef and Ardizzone 2014; Molinari 2020; Castrorao Barba and Mandalà 2023) and in the specific case of the urban archaeology of Palermo new excavations are bringing to light various aspects of the materiality of the Islamic city thanks to the discovery of ceramics, remains of buildings, Islamic burials and craft activities even outside the medieval city-walls (Vassallo 2020; Aleo Nero *et al.* 2022). It is still a challenge to document the material evidence of the Islamic period in Sicily (Todaro *et al.* 2020), particularly concerning water management and irrigation systems which have been studied especially from the point of view of written sources from the 10th-12th centuries (Metcalfe 2017; Jäckh 2019; D'Angelo and Pezzini 2020). This paper aims to summarize, from the perspective of materiality, some elements characterizing water use in Islamic Sicily and beyond, but in full awareness that in the current state of archaeological knowledge it is difficult to trace with certainty the origin and functioning of certain infrastructure connected to water management such as *qanats* or water mills to the 9th-11th century.

Underground water infrastructures in Medieval Palermo: *qanats* and more

Positioned advantageously in a lowland, Palermo historically hosted two rivers, the Kemonia (*Wādī-al-šatawī*) and the Papireto (*Wādī Barūṭa or Rūṭa*), intentionally buried later. A significant southern river, the Oreto (*Wādi ʿAbbās*), added to Palermo's hydraulic potential. Palermo's hydraulic resources are hidden within the calcarenite layers of its subsoil, comprising a system of free-flowing aquifers that are directly recharged by rainwater falling on the valley. This rainwater feeds the underground water currents, which overflow from the rigid limestone-dolomitic hydrogeological structure of the surrounding mountains (Lofrano *et al.* 2013; Todaro 2020). Together, they form a vast water reservoir, the Palermo Mountains hydrogeological basin characterized by its predominantly karstic nature (Gagliano Candela *et al.* 2024) and in the map (**Figure 1**) of the 'The Book of Curiosities of the Sciences and Marvels for the Eyes' (*Kitab gara'ib alfunun wa-mulah. al-'uyun)* dated to the first few decades of the 11th century, several springs located in Palermo valley can be seen (Johns and Savage-Smith 2003).

The underground water of the city and its valley, known as the *Conca d'Oro* or "golden basin" (Mandalà 2017), were used for irrigation as well as for the domestic needs of some urban areas, through a complex network of tunnels through which the water arrived at the surface, flowing via gravity from the water table towards the numerous artificial springs. A crucial

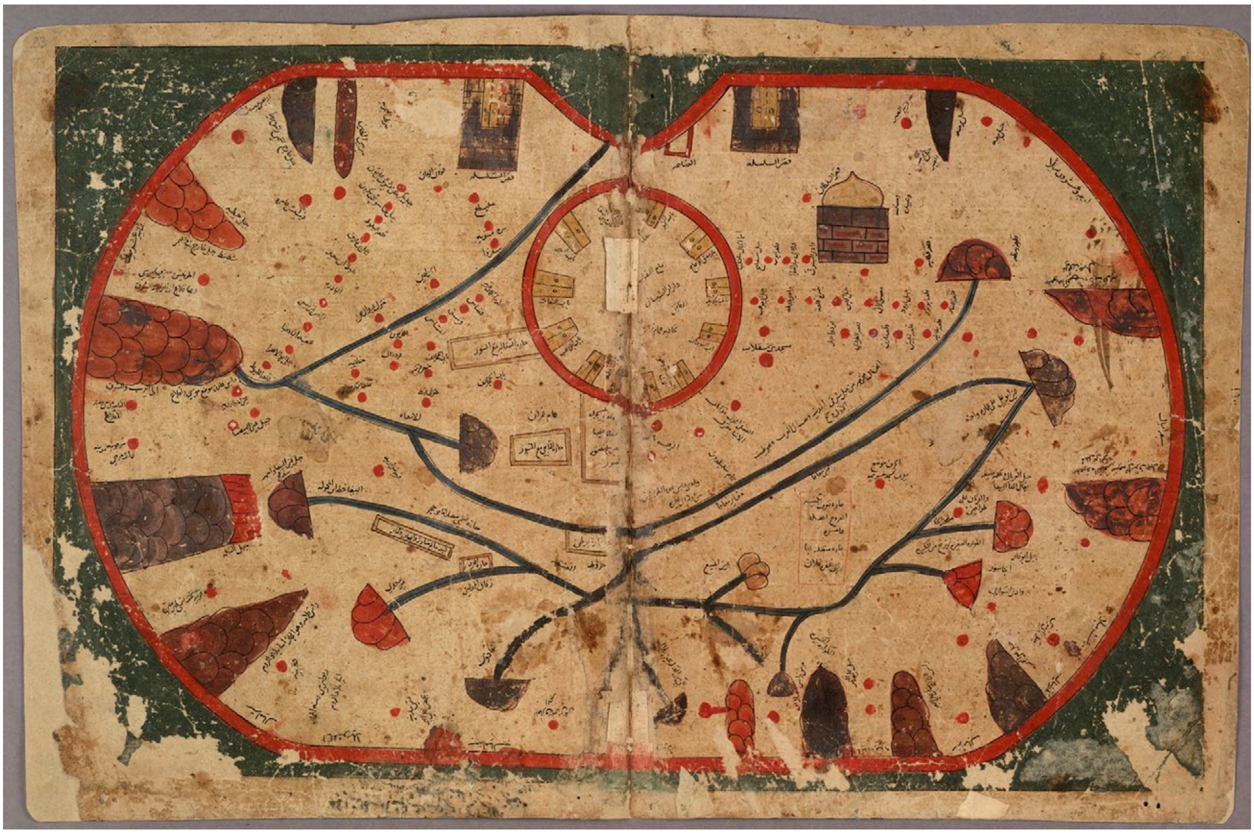

Figure 1. Map of Sicily from *the Kitāb Gharā'ib al-funūn wa-mulaḥ al-ʿuyūn* (Book of Curiosities), Oxford, Bodleian Library MS. Arab. c. 90 (https://digital.bodleian.ox.ac.uk/objects/748a9d50-5a3a-440e-ab9d-567dd68b6abb/ © Bodleian Libraries, University of Oxford, Terms of use: CC BY-NC 4.0)

aspect linking water usage to the topography of Islamic Palermo is the presence of wells. These structures are well-documented in the detailed account of Palermo provided by Ibn Ḥawqal, who visited the city in the year 972/3: 'most of the water of the city quarters and the towns comes from wells. It is rather thick and unhealthy. They drink it for lack of freshwater' (Granara 1983: 98). The ongoing urban archaeological excavations in Palermo (Piazza Bologni and Piazza Indipendenza) are unveiling a multitude of wells in the city centre, with reasonably confident dating placing them between the 10th and 11th centuries (Aleo Nero *et al.* 2020; Aleo Nero and Chiovaro 2020). This archaeological evidence further emphasizes the integral role of wells in the water management infrastructure of Islamic Palermo during this historical period.

The Palermo valley's hydrology made it possible to take advantage of both the water resources on the surface (the foothill springs) as well as underground water from the water table through the use of underground gallery systems traditionally called *ingruttati* (Todaro 2000) or generically *qanats* (Battaglia and Sammataro 2020). The *ingruttati* were dug almost horizontally into the Pleistocene calcarenite shelf of the Palermo valley until they hit the water table.

In a recent systematic review of the documentation relating to underground hydraulic structures in the Palermo valley (Todaro *et al.* 2020) it was possible to identify four macro-typologies, according to their shape and hydraulic characteristics: 1) *qanats*; 2) blind *qanats*; 3) connected wells; 4) emerging drainage galleries (**Figure 2**), but not included were isolated wells with blind tunnels at their base. In the Palermo valley, a total of 63 underground structures have been identified, classified into four categories and constructed during different historical periods. It is important to note that, based on current documentation and ongoing research, the precise construction dates of this underground infrastructure remain uncertain. However, in some instances, their first recorded use is known, allowing for a tentative chronological classification. Furthermore, some structures, particularly those attributed to later periods, may have origins dating back to earlier times. Only a small number of structures can be confidently dated, specifically those built between the 16th and 19th centuries. Overall, the surveyed or explored *ingruttati*

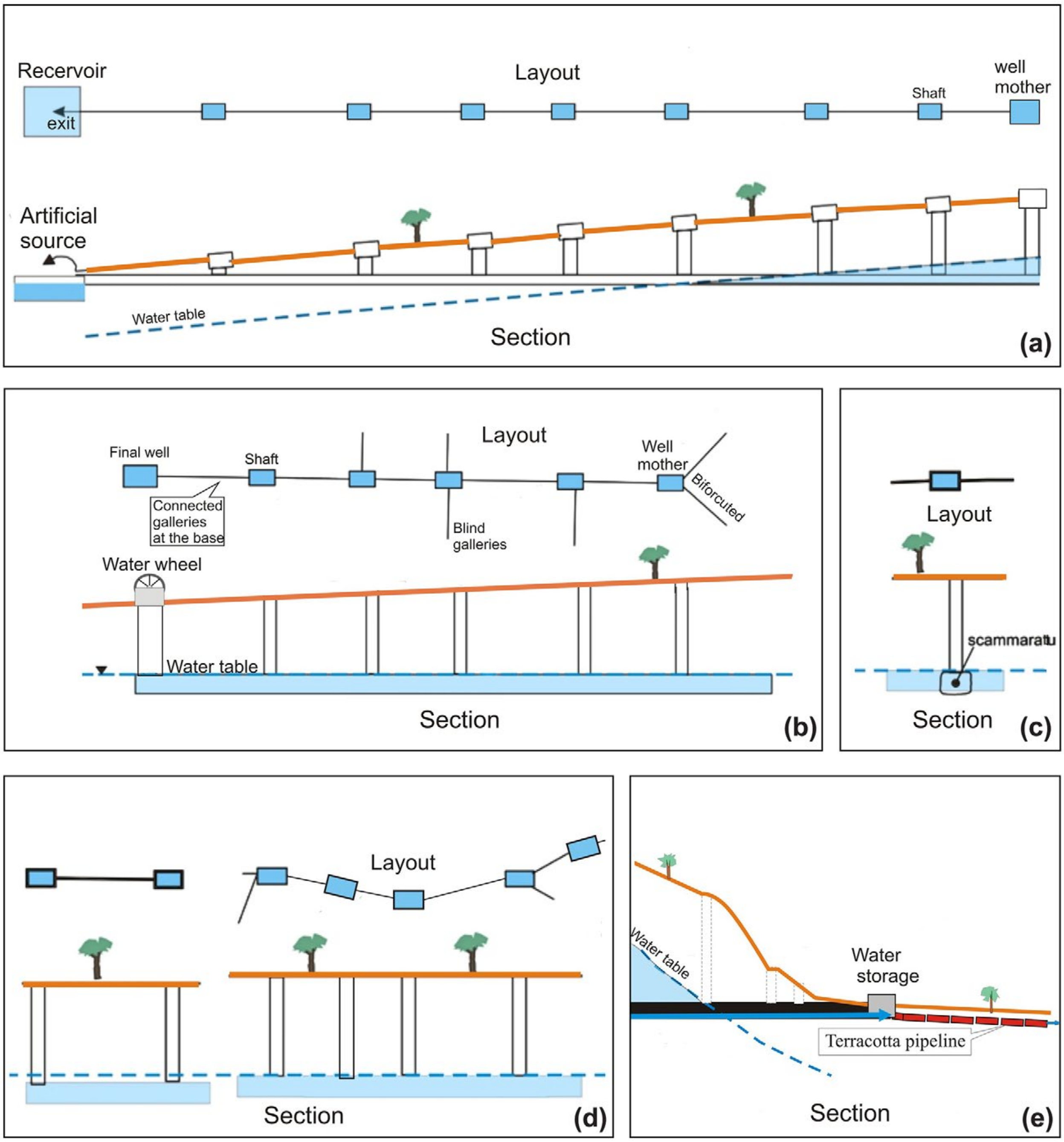

Figure 2. Typology of underground water systems in Palermo Valley (Todaro *et al.* 2020): a) *qanats*; b-c) blind *qanats*; d) connected wells; e) emerging drainage galleries.

(25 of the 63 identified structures) collectively span a length of 20323m, with *qanats* making up the majority of this network.

The first type is associated with traditional *qanats*. A *qanat* uses passive design to extract water from the subsoil, primarily utilized in large valleys. It consists of a simple 'emerging drainage gallery' that allows groundwater to reach the surface through gravity, effectively creating an artificial spring. The system includes a tunnel linked to a series of access shafts, which initially facilitate excavation (providing ventilation and debris removal) and later serve for maintenance during the tunnel's use. The gallery performs two distinct hydro-geological functions: 1) capturing and siphoning water from the water table (the shorter productive section); and 2) transporting the water flow (canal) to the outlet (a longer section). In the Palermo valley, 20 *qanats* have been identified, mostly concentrated to the west of the city. These *qanats* are found in areas ranging from 500 to 2000m above sea level, often branching into several secondary drainage channels and appendages at different levels, typically not exceeding 20m in depth. It appears that the oldest *qanats* in this group are the Danisinni and Scibene tunnels, which date back to at least the Medieval era. Mills along the Papireto-river valley, documented in primary sources from the early 14th century (Bresc 2001), could only have been powered by the Danisinni *qanat*, owing to its piezometric head—a water flow capable of providing the necessary kinetic energy for the mill's paddle-wheel. Furthermore, this *qanat* was likely already operational during the 14th century. The Scibene *qanat* supplied water to the nearby 12th-century Norman suburban palace (Scibene or Uscibene), which used it to feed its *iwan* (fountain room), likely connected to a fishery (Spatrisano 1982; Katz 2016).

The only difference between *qanats* and other emerging catch galleries like simple *qanats*, is their final outlet into small wells. In this case, the water was extracted by water-wheel systems (*senias* or *norias*). The underground sections of the structures studied vary in length from 250 to 2,000m, based on the size of the corresponding estate. These structures are mainly found in areas with a gentle slope, where the water table is relatively shallow (roughly 10m depth). A total of 13 galleries of this type (classified as 'blind *qanats*') have been discovered in several areas of Palermo, most notably in Mezzomonreale-Cuba, Piana dei Colli-Piano Gallo, San Ciro-Maredolce, and Ciaculli.

Although lesser known, there were other kinds of underground tunnels connecting to the water supply aside from the *qanats*. The Palermitan underground well and quarry diggers were able to improve the efficiency, and the flow rate of wells built in tunnels that connected multiple wells of varying distances, called connecting wells. A total of 14 connected wells have been identified, with origins traced back to as early as the 15th century. These water collection systems are dispersed throughout the Palermo valley, with the highest concentration found in the macro-area of Mezzomonreale-Cuba.

The last type is emerging drainage galleries. First utilized in ancient mining and primarily widespread in hilly and foothill regions, these galleries were the earliest method for intercepting and collecting underground water to enhance the flow rate and efficiency of natural springs. They are composed of a simple gallery or trench with a gentle slope, allowing water to flow freely toward the downstream outlet. Typically modest in length and without serial wells, they directed water to irrigation or drinking outlets via open channels (referred to as *saje* in Sicilian dialect) or pressurized closed pipes (called *catusati* in Sicilian dialect) if flowing uphill. Notably, the structure identified in Ciaculli falls into this category, associated with the historic spring known as 'small Favara'. This spring is documented on the map of the *Kitāb Gharā'ib al-funūn wa-mulaḥ al-ʿuyūn* or The Book of Curiosities (Johns and Savage-Smith 2003) compiled in Egypt between 1020 and 1050 (Bodleian Library MS. Arab. c. 90), with the Arabic name *al-Fawwara al-s.agira*. Given the hydro-geological characteristics of the area, the presence of a 'natural' spring at this site is impossible. Furthermore, the spring referenced in the 11th-century documents likely refers to a water source collected through a drainage tunnel. The spring remains active today, albeit abandoned, and its water is used to irrigate vegetable patches in the southern part of the Palermo valley through a network of primary and secondary channels, called *saje* and *cunnutii* in Sicilian dialect. A total of 16 drainage galleries have been identified in the southern part of the Palermo valley.

At a technological level, it becomes evident that not all underground tunnels, often broadly categorized as *qanats* in Palermo, are associated with the same types of solutions. The distribution of these structures across the Palermo plain reveals differences and concentrations among the four typologies, suggesting a complex chronological sequence underlying the development of this network of underground structures over time. As of now, pinpointing the exact date of the introduction of these subterranean hydraulic technologies in Palermo remains a challenging task. A more in-depth analysis of individual structures, their interrelations with existing settlements, and their absolute chronologies is imperative. At the current state of research, there are no systematic excavations or closed contexts that have allowed for absolute dating. The only reported instances are from the *qanat* of Castelforte and the blind *qanat* Scalea I, where sherds of medieval pottery (related to 11th or 12th–13th centuries) were discovered during investigations in the 1990s (Biancone and nd Tusa 1997). While the discovery of ceramics within underground channels is an intriguing aspect, without a more detailed analysis of the deposition dynamics (whether primary or secondary), these findings cannot be reliably used as chronological markers for the construction or use of the canals. In urban areas, it is common to encounter earth fillings from one period that contain older materials already present in the stratigraphic layers at the time of soil removal and subsequent reuse as fill. This complicates the use of such materials as definitive chronological indicators. To the difficulty of archaeologically dating the origin and continuity of use of these underground galleries, it should be added that medieval written sources do not seem to mention this type of infrastructure (Nef *et al.* 2021).

The intriguing possibility of a connection between certain segments of underground canals and the limited evidence of Roman structures in the Palermo plain warrants further investigation. Notably, the Roman pre-existence (a building with *opus reticulatum* wall) on the site where the Scibene/Uscibene palace was constructed during Norman times (Battaglia and Scopelliti 2017). This site exploited a *qanat* to supply water to a fountain, maybe offering a compelling link between ancient and medieval hydraulic systems in Palermo. Regarding the potential pre-Islamic presence of underground water collection technology in Sicily, it is important to note that in 5th-century BCE Greek Sicily, some major cities were already employing underground water collection systems modelled after the *qanat* design.

One notable example is the *Phaiax/Phaeax* hypogeum of the Greek city of *Akragas* (Agrigento) — a network of 27 independent drainage tunnels designed to collect and convey runoff water, filtering groundwater to create artificial springs downstream along the bed of the Hypsas river. The system (Furcas and Parello 2020) used infiltration galleries to gather water seeping through the subsoil and channel it to the surface, creating artificial springs. This design took advantage of the site's unique geological composition, characterized by permeable calcarenite layers overlaying impermeable clay deposits. Tunnels were carefully aligned along the interface between these formations, allowing them to draw water from the aquifer by capturing the moisture trickling from the surrounding surfaces. These installations enabled the accumulation of large quantities of water, functioning as critical supply points for the settlement. They also contributed to regulating subsoil water, stabilizing the geological layers, and enhancing the overall liveability of the urbanized area.

Similarly, the water supply system in the Greek city of Syracuse relied on a complex network of canals, exemplified by the Galermi aqueduct recently studied (Bouffier 2020; Bouffier *et al.* 2018). Though the available evidence dates back to the Byzantine age, inscriptions inside the rock gallery of Ciccio indicate a restoration under Emperor Constans II. Notably, after the Islamic conquest of Syracuse in 878, medieval Arab geographers make no mention of this aqueduct. The term "Galermi" *ġār al-mā* in Arabic, meaning water hole/cave/cistern, could have been applied during the Islamic period or later, and its potential use in that period remains speculative, awaiting archaeological confirmation.

In the broader context of the diffusion and origin of *qanat* technology globally (Goblot 1979), the debate encompasses Sicily. Without wanting to enter into this debate on the diffusionism or polycentrism of this technology (Boucharlat 2016; Charbonnier and and Hopper 2018), it is crucial to consider various hypotheses for the introduction of *qanats* across the long history of Mediterranean connectivity. From Greek colonization and the formation of the first Roman province to the Islamic conquest and the era under the Crown of Aragon, each period could have contributed to a diachronic succession of uses and reuses of underground water systems in Sicily. However, dating individual structures poses an ongoing methodological challenge.

Irrigation systems and Islamic Green Revolution

Addressing water and irrigation in Islamic Sicily, despite challenges in attributing certain hydraulic technologies exclusively to the Islamic period, we must delve into the debated topic of the so called Islamic Green Revolution (Watson 1974; Kirchner *et al.* 2023). In Sicily, as in other medieval Islamic regions, irrigated agriculture was pervasive, forming part of a complex productive system. New plantations, incorporating new crops and techniques, were developed, intensified, and integrated with non-irrigated agriculture and husbandry. The most significant innovation lay in irrigation systems and the proliferation of crops suitable for irrigated land. Until recently, the diffusion of some new crops listed by Watson (1983) had been only theoretical for Sicily, lacking concrete evidence. Recent analyses of excavations conducted in the 1990s in the city of Mazara del Vallo on the western coast of Sicily have provided a breakthrough. Thanks to new archaeobotanical analysis (Primavera 2018; Fiorentino *et al.* 2024), stratigraphy from the late 10th to 11th century revealed archaeobotanical remains of citrus fruits, aubergines, cotton, spinach, and watermelon. This discovery confirms the central role of the port of Mazara in the exchange network of the Islamic Mediterranean, facilitating the introduction of these new crops linked to irrigated agriculture on the Island (Molinari and Meo 2021).

Despite these new archaeobotanical data, no new 'exotic' crops have been identified at other rural settlements in the Palermo hinterland, such as the site of Contrada Castro in Corleone (Castrorao Barba *et al.* 2021; Castrorao Barba, Miccichè, *et al.* 2023). Instead, the archaeobotanical record reflects continuity between the Byzantine and Islamic periods (8th–11th centuries), dominated by cereals and legumes typical of the long-term agricultural dynamics of the ancient and medieval Mediterranean. Assessing the impact of the 'Green Revolution' in Sicily still requires more robust archaeological evidence that accounts for the contextual differences between city, suburb, and countryside, as well as micro-regional variations. Nonetheless, despite these gaps, the introduction of new crops contributed to the wider adoption of irrigation practices. In fact, the underground systems were used to exploit water in different ways, but principally to irrigate crops.

Large square water reservoirs were placed at the outlet of the *qanats*. When *qanats* ended in a well – i.e. blind *qanats* – water was drawn to the surface through water-lifting wheels moved by animals, the so called *senia/noria* system already known in the Hellenistic-Roman world (Schiøler 1973; Oleson 1984; Bouet 2005) but very common in the Early Islamic Mediterranean (Wilson 2003).

Noria (*nāʿūra*) usually refers to a large wheel that is moved directly by the river current that lifts the water up to the aqueduct. However, the same term is sometimes used as a synonym for *senia* (*sāniya*): an animal-driven (often a donkey) water-lifting wheels with bucket-chain/pot-garland machines that makes it possible to irrigate small fields by drawing water from rectangular wells and accumulating it in water tanks. This machine is quite widespread in the traditional landscape of Sicily and has been compared to Egyptian, Syrian, and probably Andalusian models. The spread of water-wheels for irrigation in the Palermo valley is testified to by Ibn Hawqal (1964) in the late 10th century. In the 12th-century description of Palermo by the Pseudo Ugo Falcando, we find a detailed description of a *senia*/*sāniya* system: 'There you can see orchards which evoke praise for the astonishing variety of their fruits, and towers made ready to guard the orchards as well as for enjoyment, and there you can also see wells being emptied, and the cisterns next to them being filled, by buckets which rise and fall as the water-wheel turns round: and the water being drawn from them through canals to different places so that irrigated plots may become green' (Falcandus 1998: 261). Also for the Norman age (late 12th century), we find in the written documentation of the boundary register (*jarīda*) of the hinterland of Palermo the mention of the ditch of the water-wheel (*ḫandaq al-dāliya*) (Metcalfe 2017: 110). From this Norman-era documentation, it has been hypothesized that in the rural areas around Palermo during the Norman period, the Muslim population made use of the *ḫandaq* system (Metcalfe 2017: 113-126), which may have originated in earlier centuries. The *ḫandaq* system was developed to enhance water availability by collecting rainfall runoff from catchment areas into specially dug trenches, supplementing supplies from rivers, springs, and wells. This method may have also helped manage seasonal flooding, as many of these trenches were likely linked to storage basins or irrigation networks that distributed water to agricultural lands. Importantly, the construction of *ḫandaqs* did not necessitate oversight or involvement from state authorities, distinguishing it from more elaborate undertakings such as aqueduct construction or *qanat* excavation.

These types of evidence of water infrastructures are, however, currently difficult to archaeologically recognize in the current landscape in terms of their materiality and chronology. Contrary to archaeological knowledge from other geographical areas of the Islamic West such as al-Andalus (Bazzana *et al.* 2009; García Blánquez 2015), no structural evidence of Medieval water-wheel machines have been found in Sicily. Only in the medieval reuse of the Temple of Asclepius, located on the plain in front of the hill of the Valley of the Temples in Agrigento, has the presence of a *senia* well been hypothesized, inside which six *senia* pots were also found (Ardizzone 2020). Instead, their existence during the Islamic period is documented by the discovery of some of their components such as the ceramic buckets / *senia* pots: *qâdûs* in Arabic, *arcaduz* or *cangilón de noria* in Spanish (Rosselló Bordoy 1992) or *vaso da senia* or *noria* in Italian. Even for this type of artefact connected to the water-wheel, the documentation and typological seriation is much richer for al-Andalus (Gutiérrez Lloret 1996; Blanquez 2015) than for Sicily where this type of pottery has been found mainly in Palermo in archaeological layers of the Islamic period (**Figure 3**).

The discovery of *senia* pots in excavations at Castello San Pietro (Arcifa and Bagnera 2014), the church of Santa Maria degli Angeli della Gancia (Ardizzone *et al.* 2014), and Palazzo Bonagia (Sacco 2014) in Palermo, dating to the late 9th-early 10th century, provides valuable evidence of this technology's presence during the Islamic period in Sicily (Arcifa 2010). These *senia* pots look typologically distinct from those in al-Andalus and more closely resemble examples from the Maghreb or Egypt or Syria. Similar finds have been recorded in other urban excavations in Palermo, including Piazza della Vittoria (mid-10th-mid-11th

Figure 3. Senia-pot from Islamic context of Castello S. Pietro in Palermo (Arcifa 2010: 124, fig. 22-24).

century, Aleo Nero and Vassallo 2014), Via Castello (10th-first half of the 11th century, Vassallo *et al.* 2019), Via Torremuzza (second half of the 10th-early 11th century, Pezzini 2004) (the Archaeological Museum excavations (second half of the 10th-early 11th century, Lesnes 1997), SS. Trinità/Magione (11th-12th century, D'Angelo *et al.* 1997), the Norman *hammam* of the Zisa palace (12th century, Falsone *et al.* 2022) and Maredolce palace (13th century, Tullio 1997). Beyond Palermo, *senia* pots have also been identified in urban contexts near Mazara, dated to between the late 10th and early 12th centuries. The identification of *senia* pots serves as important material evidence of the diffusion of this irrigation system also into the countryside. Notably, these ceramic artifacts hold significant relevance in phases linked to medieval settlements, such as those that developed atop the remains of the late Roman Villa del Casale of Piazza Armerina in Enna Province (second half of the 10th-11th century, Bonanno 2020), and at the castle of Calathamet in Trapani Province (11th-12th century, Lesnes *et al.* 2013). The presence of *senia* pots highlights the rural communities' adoption of water-wheel technologies, most likely for irrigation purposes.

This irrigation method by *senia-noria* system is still used in Sicilian traditional citrus farming with a lexicon that continues to hark back to ancient Arabic (Barbera 2007). Water flowed out from a spring (it. *favara, ar. fawarra*) or was drawn by a waterwheel (it. *senia,* ar. *saniya*) placed on a raised embankment so that the water would spill into a large basin (it. *gebbia,* ar. *gabiya*), after being poured into a *gibbiuni* that would make it possible to ration it, it would be carried along open channels (it. *saja,* ar. *saqiya*) and terracotta pipes (it. *catusi,* ar. *qadus*) shaped like overlapping truncated cones that made the pressurized transport of water possible so that it could reach uphill land at higher elevations, finally reaching the watering basins around the trees that are divided by low earthen berms called *vattali* (*batil*). Water is measured in '*zappe*' (*sabba*) equal to four *darbi (*darb). This type of hydraulic technology represents a defining feature of Sicily's traditional historical landscapes

Figure 4. Sicilian traditional irrigation systems: an abandoned *saja* (water channels) inside the Favorita Park in Palermo (photo. A. Castrorao Barba).

(**Figure 4**), serving as a valuable biocultural heritage that must be preserved.

Water mills

Another important aspect of water management is the use of water power to operate horizontal mills. The origins of this water mill technology in Sicily remain uncertain, although numerous examples of such structures are documented across the region (Bresc 2001). In the *Kitāb Nuzhat al-mushtāḳ fi 'khtirāḳ al-āfāḳ* (so called *The Book of Roger*) by al-Idrīsī completed in 1154, there are numerous mentions of watermills in different locations on the island (Trabia, Brucato, Cefalú, Naso, Olivieri, Messina, Catania, Noto, Caltabellota, Partinico, Mainaci, Cerami) and obviously also Palermo for which he wrote: 'beyond the suburbs to the south is the Oreto [*'Abbās*] river and this is a running river upon which there are mills that are sufficient to meet the needs of the city' (Jacka *et al.* 2024: 79). Some may date to the late medieval or early modern periods, but precise chronologies are often lacking due to the absence of systematic archaeological studies. A notable case are the water mills in the rural district, or *iqlīm*, of *Qurliyūn* (present-day Corleone) (Ridulfo 2007), situated in the inland area of the Sicani Mountains, which was conquered by Aghlabid forces in 840.

Within the framework of research on the formation of Islamic landscapes in Western Sicily (Castrorao Barba *et al.* 2024), connections between rural settlements with evidence of 10th- and 11th-century occupation and the monumental remains of certain water mills are being explored (**Figure 5**). While Norman sources from the 12th century confirm the operation of these mills during that period, the hypothesis that their initial use occurred in the Islamic era remains unproven. Nevertheless, these preliminary observations underscore the potential for future archaeological research to enhance understanding of their historical significance and role in the landscape. The water mills were designed with horizontal wheels powered by water flows diverted from streams and channelled through conduits, in a manner similar to the *saje* system associated with the *senia* or *noria*. This effective and enduring technical solution persisted throughout the Middle Ages and

Figure 5. Watermill in the territory of Corleone (photo. A. Castrorao Barba).

Figure 6. The palace of Maredolce-La Favara viewed from the artificial lake with a sort of island in the middle (photo. A. Castrorao Barba).

the modern period, highlighting the importance of further studies to examine its relationship with the development of Islamic landscapes in Sicily.

Water use beyond the agriculture

While water management in Islamic Sicily was pivotal in both agricultural and urban contexts, its applications extended beyond these domains. A remarkable example is the use of a natural thermal water source near Cefalà Diana, an inland area of Palermo, for a dedicated *hammam* during the Islamic period (Bagnera and Nef 2018). This site later witnessed the construction of a monumental building by Norman royal authorities in the 12th century, reflecting the continuity of water-related practices. The Norman kings of Sicily effectively integrated elements of Islamic culture into their architectural and symbolic representations of power. This cultural assimilation is particularly evident in the design of gardens and water management systems, underscoring the lasting influence of Islamic traditions on the Norman architectural and cultural landscape in Sicily. In the description of Palermo, al-Idrīsī dwells on the presence of water and springs and underlines that 'the city's fruit are abundant and its buildings and parks so lovely that they dazzle those who try to describe it', on the same line Ibn Jubayr who visited Palermo in the late 12th century, described it as 'proudly set between its open spaces and plains filled with gardens' and 'the King's palaces are disposed around the higher parts, like pearls encircling a woman's full throat' (Ibn-Ǧubair and Irwin 2020: 368). Maybe replacing an area with aristocratic palaces surrounded by gardens of the Kalbid era (Bagnera 2013), a suburban royal park called *Viridarium Genoard* (from the Arabic *jannat al-arḍ*, meaning "Earthly Paradise / Garden") (Mandalà 2017), provided the setting for the construction of Norman recreational estates so-called *solatia* — the Cuba, the Cuba Soprana, the Zisa, Uscibene, and Maredolce — similar to Islamic *almunias-munyas* or *basātīn* (Navarro Palazón *et al.* 2022), that exemplify the enduring influence of Islamic design and landscaping concepts in 12th-century Palermo.

An essential example of the synergy between water management and royal architecture during the Norman period is the Mare Dolce–La Favara palace (**Figure 6**), situated in the southern suburbs of Palermo (Barbera *et al.* 2015). The term *fawwāra* – which means a jet of water or bubbling spring in Arabic– is a very common hydronym in Sicily. In fact, historic documentation from the Islamic period (the map of *the Book of Curiosities* and Ibn Ḥawqal) identifies two springs, the Big Favara (*al-fawwāra al-kabīra*) and the Small Favara (*al-fawwāra al-ṣaghīra*) (Johns and Savage-Smith 2003). The original structure, compact and solid, dates back to the Islamic era and was built on what was likely a Roman farm (Canzonieri and and Vassallo 2014). This site may correspond to the remains of the *Qaṣr Ja'far* associated with the emir Ja'far ibn Yusuf (998–1019), mentioned by Ibn Jubayr in the late 12th century that locate this castle in the outskirts of Palermo and characterized by the presence of a spring or a pool of sweet water (Ibn-Ǧubair and Irwin 2020: 366).

During the reign of Norman King Roger II (first half of the 12th century), the site underwent a dramatic transformation in appearance and functionality, marking one of the earliest and most significant hydrological renovations in the Palermo valley. Spring water was channelled into a large basin, and substantial earthworks were carried out to regulate the lake and prevent uncontrolled flooding. A dam, constructed from large ashlars coated with impermeable pink plaster, was built along the coastal side, where the natural slope allowed water to accumulate. The design and construction of the Maredolce lake represent a major hydraulic engineering achievement involving dam construction and the enhancement of agricultural land (Todaro *et al.* 2020). These efforts required significant investment of time and resources, as the project involved extensive excavations and earthworks. At the centre of the excavated depression, vertical walls lined the edges of a triangular islet situated within the reservoir. Interestingly, this islet bore a resemblance to the shape of Sicily, as depicted in the map of al-Idrīsī, the geographer at Roger II's court. The lake served as a vast irrigation reservoir, supplied by *senias* and canals, and was also used as a fishery. In a poem by 'Abd ar-Raḥmān al-Iṭrābanišī, known as the 'Trapanese Secretary' and a contemporary of Roger II, the opening verse refers to two seas: 'Oh Favara of the Two Seas, you gather every blessing: a life of delight and a supernal sight / Your waters split into nine streams, how perfect their divided flow / The meeting of your Two Seas is the battleground of Love, on your Two Shores passion has encamped' (Carpentieri 2018: 10). An intriguing hypothesis is that this 'double seas' reference might describe a deliberate design intended to create an 'infinity pool' effect, visually connecting the lake to the Tyrrhenian Sea (Tito Rojo 2018).

Conclusions

The archaeological evidence for water management and use in Islamic Sicily reveals numerous gaps and unanswered questions. While written sources—particularly those concerning Palermo—offer references to water management systems and infrastructure, the archaeological record remains notably underdeveloped. The identification of medieval wells during rescue excavations in Palermo and the discovery of *senia* pots in urban and rural contexts, dating from the late 9th century to beyond the 12th century, provide valuable evidence. These findings confirm the presence of water-lifting wheels with bucket-chain or pot-garland mechanisms in Islamic Sicily. However, it is evident that further archaeological research is essential to better understand the methods and chronological aspects of water management practices. The dating of many underground water systems in the Palermo Valley remains unresolved, with uncertainties regarding both their origins and the continuity of their use over centuries.

To address these issues, a dedicated research agenda is required, incorporating archaeological and archaeometric methodologies. Such an agenda would enhance our understanding of these infrastructures and situate the Sicilian case within the broader context of the diffusion of hydraulic technologies across the Mediterranean and Euro-Asian regions (even beyond). Similar challenges exist concerning water mills, where chronological and stratigraphic data are equally scarce. These uncertainties, however, represent both a challenge and an opportunity to apply archaeological methods to the study of water management during the Islamic period, as well as in the Norman era, where monumental examples are evident in suburban palaces (*solatia*). Finally, the enduring legacy of certain irrigation practices in the traditional Sicilian rural landscape provides a crucial link between the past and contemporary society. This connection highlights the importance of preserving the biocultural heritage of the countryside while encouraging sustainable water management practices for future generations.

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Chapter 13.
Interpretational Correlation between the Hydrological Infrastructure and Water Architecture in Islamic Alexandria within a Contemporary Urban Context

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Introduction

Water efficiency has accompanied human civilizations and activities since the dawn of history. The distant location of Alexandria from a sustainable water source provoked the city to be connected to the nearest branch of the River Nile, the Canopic, through the Schedia Canal in the Ptolemaic period (4th century BCE).

Islamic Shari'a regulates water human rights, which motivated Muslims to share and facilitate water for humans and living organisms without charge. In terms of management and mechanism, Muslims in Alexandria adopted pre-Islamic traditions of water management. The maintenance of Alexandria's water infrastructure has been upgraded since the Islamic Conquest in the seventh century (all dates are CE unless otherwise specified). The pre-Islamic cisterns were utilized in addition to constructing new cisterns dedicated to providing water for mosques and *sabils* (fountains). Muslim architects innovated *sabil* architecture to provide water for passersby for free as a type of charity. The functional diversity of water facilities in Alexandria led to innovations in water management techniques.

The government made significant efforts to clean canals and cisterns on a mass scale, while people innovated natural methods to purify water inside their homes. Water processes were organized by groups of specialists aligned in a hierarchical system similar to socio-labour unions, '*ṭwā'īf al-ḥīrāf*'. Governance of water process was fundamental and a market Supervisor, '*Mūḥtāsīb*', was in charge of inspecting all markets and crafts, including those related to water process. The *Mūḥtāsīb* had absolute power to fulfil his responsibilities. Retrieving historical conceptions of water could contribute to solving water problems. Furthermore, a deeper understanding of the building materials of water architecture supports eco-architecture endeavours.

This contribution provides insight into the historical innovations tackling water management in Islamic Alexandria. The discussion of technical treatments and administration outlines its historical context and progression. Moreover, from a future perspective, a deep understanding of the historical water process conceptions and the building materials that were utilised may help solve contemporary water problems with which the world is being confronted.

Water infrastructure: The inter-relation of water scarcity and cityscape

The disadvantage of the location of Alexandria is its distance from the River Nile or any other fresh water source. As a result, fresh water infrastructure was essential to develop the city during the Ptolemaic period.

Topographic and urban formulation

Alexander the Great admired a narrow strip of land between the Mediterranean Sea to the north and Lake Mareotis to the south as an ideal strategic location for a new city, Alexandria. Alexandria has access to the Mediterranean through two harbours as well as access to the rest of Egypt via the inland harbour on Lake Mareotis. Alexander appointed Dinocrates of Rhode in 332BCE to plan his new city, according to the Hippodamian pattern of city planning (Escoffey 2012: 10). Ptolemaic erected splendid buildings, such as the magnificent lighthouse of Pharos. The Heptastadium, a thick wall, linked Pharos with the mainland and encompassed the Great Harbour to the east and Eunostos Harbour to the west. The integrated water system consisted of a canal, conduits, and cisterns and conducted fresh water from the River Nile to the waterless city. (Escoffey 2012: 8).

Alexandria declined after the Islamic conquest in 641. The city was growing steadily during the successive Islamic dynasties - Tulunid, Fatimid, Ayyubid, and Mamluk (9th–16th centuries) - when the city was reconstructed. 'Alexandria should only be seen as

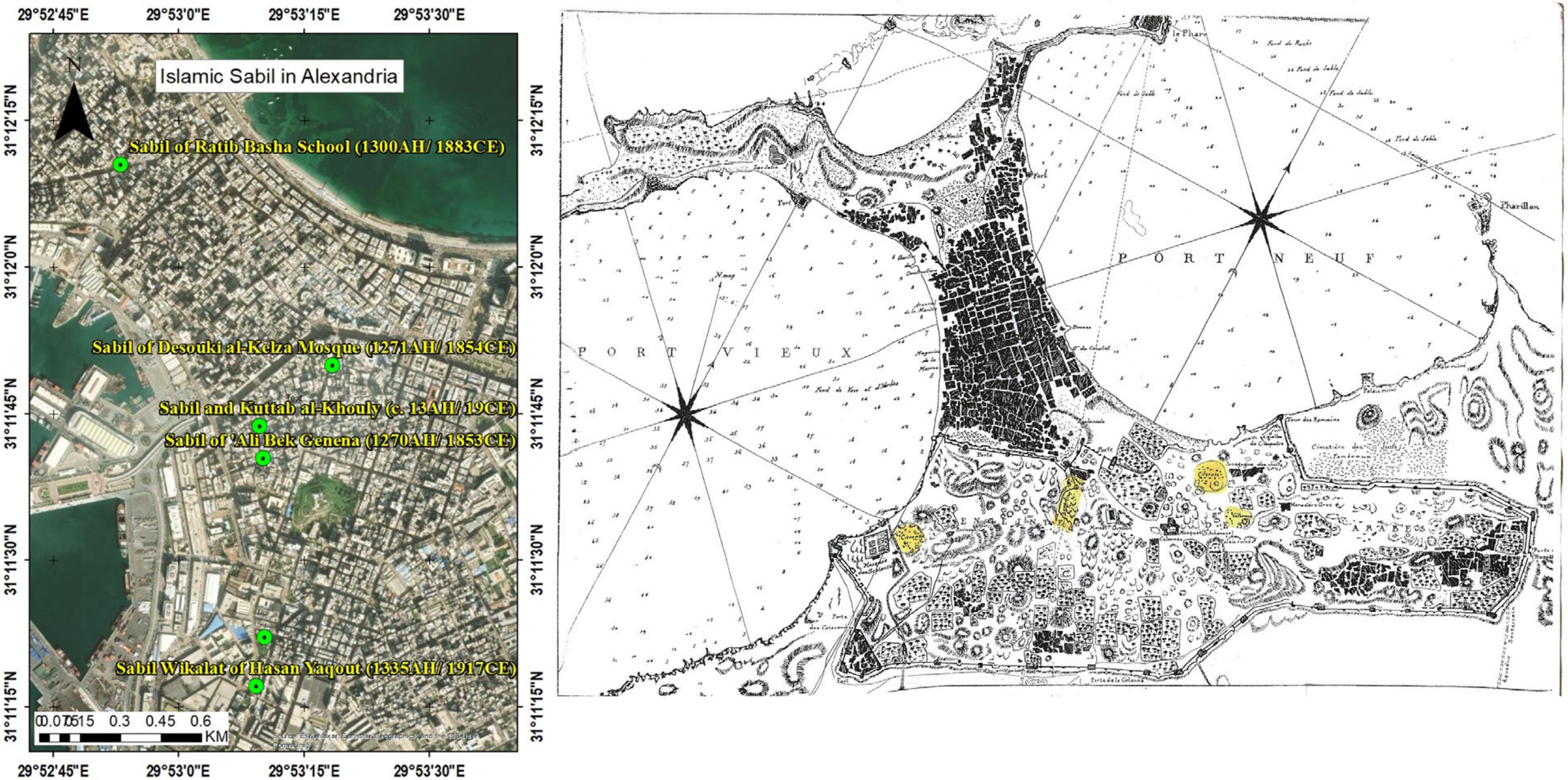

Figure 1. 1. Cistern locations in Alexandria. 2. Cistern agglomerations inside the ancient walls on the Napoleonic Map (1801).

a warehouse of goods', Gratien Le Pére (1826: 381) expressed about the Ottoman city in 1798. The urbanism of Alexandria has changed over time as a result of war, economic decline, and natural hazards that created 2–10m depth of multi-archaeological layers, as well as submerged antiquities. However, ancient historical landmarks still stand in Alexandria such as Pompey's Pillar, the Catacombs, and the Roman Theatre (Soliman et. al.: 2020: 1-8). Human activities created Kom al-Nadoura and Kom al-Dikka in the late Roman and medieval periods and both mounds were used as sailing landmarks (Léon 1983; Le Pére 1826). However, sand accumulation formed most of the hilly land of the premodern city in the 19th century and mounds extended (SW/NE) to the north of the *Canal d' Alexandrie* outside the south wall of *Enceinte des Arabes*. Likewise, at Ras al-Tin, west Pharos Island, which Mohamed Ali began removing in preparation for constructing the Ras al-Tin Palace in 1830, and by the early 20th century these mounds were gradually disappearing (Soliman et. al.: 2020: 1-8).

The compact urban fabric, known as *Ville Moderne* (modern city), is concentrated in the northern part of the city (Le Pére 1991). Six neighbourhoods were scattered inside *Enceinte des Arabes* (the ancient Arab city); four existed next to the main gate for accessibility and local trade consideration; two west to Porte de Rosette, two north to *Porte de la Calonne* (**Figure 1**). The urbanism of Alexandria was limited between the eastern and western ports in the early 19th century, known as "The Turkish City," where the Gomrouk Neighbourhood is now located. Geologically, the Turkish City was formed after the destruction of the Heptastadium, and sea sediments accumulated gradually until it became the largest inhabited urban area in the early 19th century. Alexandria then developed from a town with no more than 7,000 population to a modernized city and the second capital of Egypt, thanks to development projects including improving water infrastructure which was prioritized. The digging of the Mahmoudiyah Canal in 1820, almost at the same watercourse as the old Canal of Alexandria, attracted developers to invest everywhere in the city. Consequently, the population increased to 40,000 and jumped again in 1840 to 60,000, reaching 143,000 in 1848. (Al-Sarouji 1963: 359)

Urban growth accelerated in Alexandria during the reign of Khedive Ismail and compared to his ancestor Said Pasha; the urban area quadrupled. Development projects contributed expansion in urbanization and enriched economic life. Extending a local railway system upgraded the urban mobility between medieval Alexandria and its new eastern suburbs. In addition, al-Ramel tramway added value to grow al-Ramel suburb in 1860. The foundation of the Alexandria Water Company in 1879 revolutionized the freshwater infrastructure in the city. Consequently, a sewage network was extended all over the city. Moreover, Khedive Ismail permitted Eugene Lebon, a French developer, to create the company for lighting Alexandria and its suburb in 1865. (Al-Srouji 1963: 372).

This urban growth continued during the early 20th century, mainly because of economic prosperity in the city as the principal harbour of Egypt. Industrial growth enhanced quality of life, where Alexandria was home to 40% of the national industry. On the other hand, developing the seashore road in 1934 connected two royal palaces, Ras al-Tin in the west and al-Mountaza in the east. This road linked all urbanized neighbourhoods in Alexandria and increased opportunities to develop the uninhabited areas, and immigration to the city increased after Alexandria University was established in 1942 (Rizk 2001: 31).

Depicting water infrastructure

Water network construction

The location of Alexandria away from the River Nile revealed the need to secure a sustainable water source to feed the new city in 331BCE. The Canopic branch was the nearest Nile branch to the city, and where the Schedia Canal, the first in Alexandria, was dug in 331BCE. Nineteenth century scholars indicated that the Schedia Canal extended for 27km from Kom Al-Hamar (Kom al-Giza) on Rosetta Road along the Mediterranean Sea westward to Alexandria. ('Awad 1963: 17; Toussoun 1942: 8-9). The Schedia Canal supplied Rhacotis suburb, the southern neighbourhood, and its surroundings with fresh water and through twelve subterranean conduits that were buried in the 20th century due to

Table 1. The six major reclamation projects during the Islamic Period.

Developer	Period	Contribution
Al-Harith ibn Miskeen	Abbasid (239-245 AH/853-859CE)	Re-digging the main watercourse
Ahmed ibn Tulun	Tulunid (259AH/872CE)	
Al-Hakim bi-Amr Allah	332 AH/846CE	Cleaning
Al-Zahir Baybars	662 AH/1263CE	Cleaning and enlargement
Al-Nasir Mohamed	710AH/1310CE	Cleaning and deepening

the developing new street network (Ferro and Magli 2012: 383). Strabo indicated that the Schedia Canal is a human-made river that runs parallel to the southern wall of Alexandria penetrating it beneath the urban area northward and splitting into subterranean conduits that feed cisterns beneath the city, securing fresh water for the population throughout the year (**Table 1**) (Marlowe 2012: 61; Al-Shayyal 1967: 82-83).

A vestige of the Canopic branch downstream from Schedia appears to have survived into the 13th century, or at least to have been revived by then in canalised form, which means the Canopic branch disappeared by the 13th century, entirely (Cooper 2008: 59-60). As a result, the intake point of the Canal was shifted eastward on the Rosetta Branch at al-'Utaff village, when Sultan al-Nasr Mohamed ibn Qalawun re-dug the canal and attributed it to his name, Khalij al-Nasri in 710AH/1310CE (Al-Qalqashandī 2004: 304-305). Since then, the intake and estuary points of the Schedia Canal survived until the digging of the Al-Mahmoudiyah Canal in the early 19th century (Toussoun 1942: 8-9). Nevertheless, during the Islamic period, maintenance projects were carried out in the canal, so that these projects were indicators of the power and authority of the ruler himself. Al-Maqrīzī summarized six main contributions since the Abbasid period (132AH/750CE), but al-Nasir Mohamed's project was the most effective (Al-Maqrīzī 1987: 171-172; Salem 1963: 301-302). However, Severus reports that Egypt's Umayyad ruler 'Abd al-'Aziz (684/5-705) had the channel excavated from the mouth of Nafltah [i.e. Naqidah] to Alexandria - that is, along its entire length. (Cooper 2008: 59-60).

Water networks were developed to conduct large amounts of fresh water to urban areas of high consumption for irrigation, drinking, and other daily uses. Twelve conduits run under the street network and Sans-Gêne , the Chief Officer of Roads and Bridges Construction of the French Campaign (1798-1801), described conduits that extended eastward to Cape Lochias in the al-Silsilah area and poured into the eastern harbour (*Description de l'Egypte* 2003: 219). Whilst the Cartography of Alexandria illustrated five main conduits that ran beneath the city, which were working until the 19th century (Al-Falaki 1967: 145). Conduits are frequently discovered by chance. During development of the National Hospital in Alexander the Great Street, ancient ruins were revealed that matched their paths illustrated in Falaki's map. The conduits were built of limestone coated with impermeable plaster and covered with a gabled top. A square maintenance shaft discovered in one allowed cleaning and maintaining annually before receiving the new Nile flood (Tkaczow 1993: 148).

Hydro-urban Mobility

Canal projects in Islamic Alexandria were supplemented by bridge (*Qānaṭir, Qānṭārā*) and embankment (*Jisr, Jusur*) building to facilitate mobility above the canal of Alexandria and its branches.

There were two types of embankments; one constructed of wood across wide canals. Wooden ships fixed on the bank were sunk and covered with compressed sand. The other type was of masonry built above narrow channels (Nawar 1999: 50-51). Functionally, Ibn Mammātī (d. 1209) differentiated two types of *jusur*, Sultani and Baladi. Sultani Jisr was managed by the central government, while the Baladi Jisr was the responsibility of local feudal lord. Sultani Jisr served canals between villages and was monitored and maintained by the central government all over Egypt who appointed a prince '*Kashif Jusur*' for each province to be responsible for reclaiming its embankments, annually. Whereas the annual maintenance of the Baladi Jisr because it served specific villages unconnected to another was the responsibility of feudal lords. (Al-Qalqashandī 2004: 448)

The long extension of the Canal of Alexandria and its branches also required bridges. These were built of stone or fired bricks with one or two arches or more constructed upon strong foundations (Abdultawab 1963: 9-10). Four *qānṭārā* were erected above the main conduits of the canal of Alexandria outside the city walls. Al-Falaki Pasha confirmed the location of these *qānṭārā* aligned to the main roads of ancient Alexandria, indicating their authenticity. Moreover, an urban area was developed outside the walls between the Canal and Lake Mareotis, where an avenue extended from the last *qānṭārā* parallel to the cross roads of the city towards the sea (Al-Falaki 1967: 146).

Water storage process

The cartography of Alexandria indicates the density of cisterns as in the maps of James Wyld (1802) (**Figure 2**) and W.H. Smyth (1843) (**Figure 3**). Moreover, the detailed and accurate Napoleonic map (1801) (**Figure 1**) emphasized three cistern agglomerations inside the walls. One located to the west where the al-Gharabah cistern survived, and two other clusters located to the east around the cistern of al-Nabahna. The official historical statistics also provide different estimation for the cisterns of Alexandria. Henry Blent, the British explorer who visited Alexandria in 1634, estimated that 500 of the 2,000 cisterns survived (Empereur 1998: 126). While the French Expedition (1798-1801) estimated 308 cisterns (Description de l'Egypte 2003: 267). In contrast, Mahmoud Pasha al-Falaki (1866) reported a higher number, c. 700 cisterns. (Al-Falaki 1967: 89).

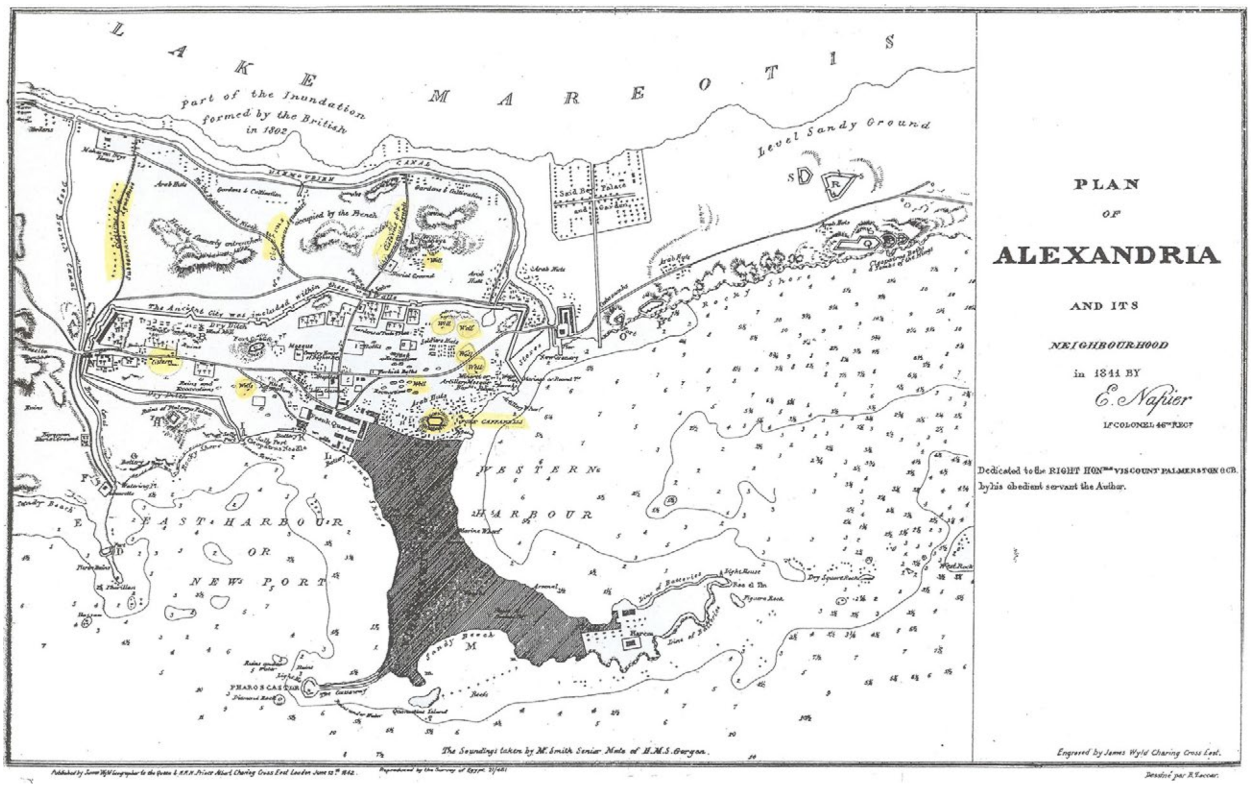

Figure 2. Cisterns assembled alongside the conduits inside the walls on James Wyld map (1802).

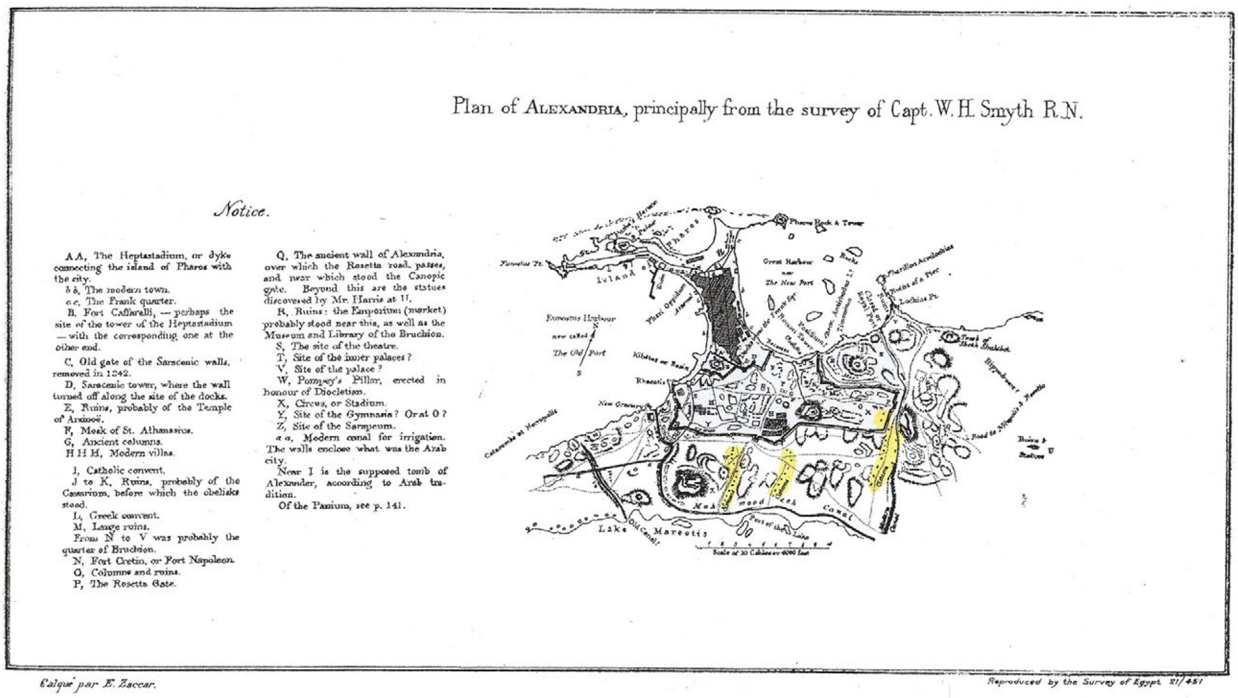

Figure 3. Cisterns assembled alongside the conduits inside the walls on W.H. Smyth map (1843).

Table 2. 19th century cistern statistics.

Year	Affiliation	Number
1801	The French campaign	308
1834-1848	Galles Bey	896
1866	Mahmoud Basha El-Falaky (the astronomer)	700
1864	Henry Blent	500 of 2000
1905	Comité de Conservation des Monuments de l'Art Arabe	126

However, Galice Bik, the chief engineer of Mohamed Ali, provided a larger number of 896 cisterns, which Ali Pasha Mubarak estimated as a modest amount and just 300 of which survived (**Table 2**) (Mubarak 1981: 99). Nevertheless, varied cistern statistics do not reflect the growth of cistern construction but instead indicate the utilization of ancient cisterns according to the required water consumption, annually.

After the establishment of the Alexandria Water Company in 1879 the water infrastructure system was converted to pipelines. As a result, cisterns became unfavourable and were seen as hindering modernizing Alexandria. Therefore, the *Comité de Conservation des Monuments de l'Art Arabe* aimed to rescue the cisterns of Alexandria as outstanding heritage. The *Comité* stipulated that the Ministry of Public Utilities report requests of developers in Alexandria, before giving a license. The *Comité* investigated architectural drawings and reports which helped estimate the number of surviving cisterns and decided to preserve 23 of 126 in 1900 (The Comité 1902: 12). Further French research has identified others (**Table 2**) (Empereur 1997: 184).

Water facilities: Diversity in function and architectural patterns

The topographic and urban transformation of Alexandria generated diverse water architecture, and the surviving water system provides a holistic perception of its significance.

Characteristics of Alexandria storage system

Functionally, the cisterns of Alexandria were classified as governmental 'Sultani' and social 'Baladi'. A Sultani cistern was utilized for two purposes; to serve water for civil use under governmental supervision; and to secure fresh water for the troops in the fortifications of the city, and these were usually smaller than the cisterns for civilian use. The Baladi cisterns were also smaller than Sultani ones as they were utilized to serve a single building, usually mosques, *sabil*, and houses.

Cisterns outside the walls were also used to irrigate orchards and gardens. These were originally part of the water network of the city, but following urban shrinkage during the Ottoman period, when people abandoned the old city and moved to inhabit the new Turkish area northward, people who owned lands in the old city utilized the neglected cisterns to irrigate their orchards (Shari'a Records 1012 AH: 953). Shari'a Court records also refer to cisterns dedicated to irrigating green lands. A contract of buying a garden in the al-Gazira area included a cistern for irrigation fed with water from the al-Qassab Sultani cistern (Shari'a Records 1046 AH: 699). Furthermore, reports of the *Comité de Conservation des Monuments de l'Art Arabe* in 1901 mentioned a cistern located in a garden of Mohamed Mustafa Qabudan in Bab Sidra al-Guani (The Comité 1904: 97).

The architectural design of cisterns in Alexandria was influenced by the topography and geology of the location, and the cisterns can be classified into four types. i) Uncoated rock cisterns characterizing the early Greco-Roman period, designed in one irregular space and of low capacity. The reports of the *Comité* refer to one of these rare types of cisterns located in Zawiat Sidi Wanas. ii) Plastered rock cistern of the same date as the first type but coated with impermeable plaster '*Saroj*'. The *Comité* observed several of this type, but most have been demolished such as the al-Toba cistern in Kom al-Nadoura area, while the *Comité* preserved the oldest one in the Serapeum of Pompey's pillar that dates back to the 5^{th} century. The Serapeum cistern is distinguished with a vaulted ceiling not natural rock as would be supposed (The Comité 1900: 83). iii) Block type: cisterns beneath houses and mosques are of this type and served minimal consumers. Hence their small ceiling width did not require columns as support. The cistern of the al-Busairi mosque (1743) is a typical example. iv) Columned pattern: These had a large span and huge capacity and required complicated architecture. They were common in the Byzantine and Islamic periods in Alexandria. Columns supported the ceiling of a single-story cistern, as well as superimposed arcade cisterns that would rise to four levels (**Figure 4**).

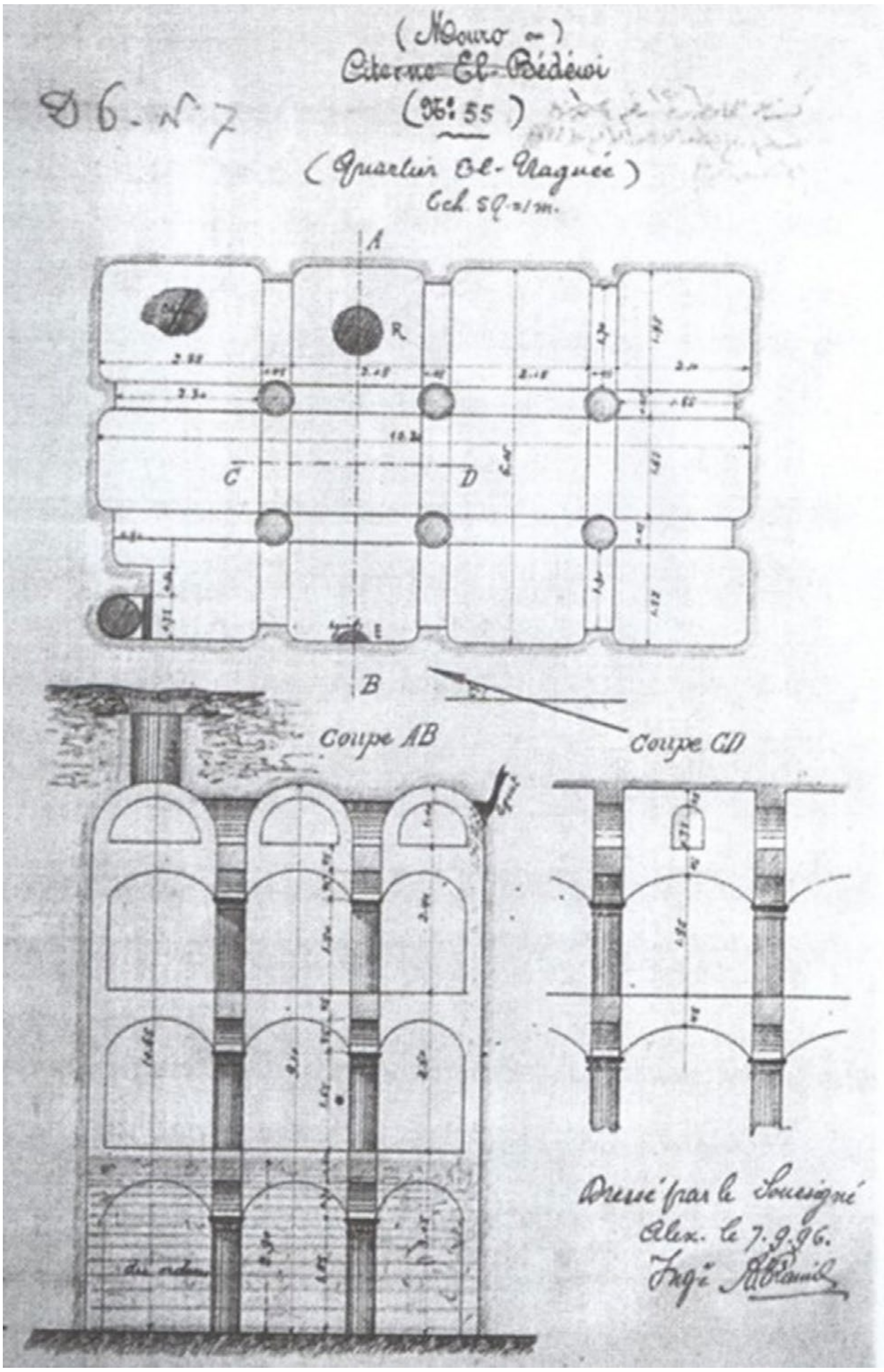

Figure 4. Morwro cistern: a demolished superimposed arcade cistern of four levels (Kamil 1898).

The typical design of larger Sultani cisterns consists of square spaces covered with shallow domes or vaults lifted above recycled columns from abandoned ancient buildings. The vast majority of surviving cisterns, as well as those reported in documents in Alexandria follow this pattern. Downtown Alexandria contains a high density of Sultani cisterns and five are listed as national treasures. Al-Nabih cistern (5th century) (**Figure 5**) is the most significant surviving cistern, which consists of three floors of recycled columns and a shallow domed ceiling with a central rectangular well and five circular wells to extract water out of the cistern. The cistern of Hajj Terbana Mosque (1097AH/1685CE) is another splendid example (**Figure 6**). Although it contains one single-floor, but it mirrors the characteristics of mosque cisterns in Alexandria.

Figure 5. A surviving superimposed arcade cistern of Al-Nabih.

Consequently, Alexandria cistern designs have different planning. Max Herz, chief architect to the *Comité de Conservation des Monuments de l'Art Arabe*, illustrated various cistern plans in Alexandria in the technical report no. 238 in 1898. Herz concluded that there were four types: irregular, square, rectangular, and circular. Herz relied on the endeavours of the architect Azmi Kamil, who was assigned by Ministry of public Utilities to document the cisterns with architectural drawings in 1898.

Sabil architecture: social solidarity for water

Providing free fresh water for passersby corresponds to charitable Islamic ethical values. The necessity of a devoted structure became fundamental in Islamic cities. To fulfil this intention, the *sabil* was the appropriate architectural pattern. Alexandria had numerous of these, as it can be claimed that a *sabil* was fixed to every building in Alexandria. Furthermore, the interests of the water donors included animals, and another good deed was to devote a *sabil* to providing water to animals. Consequently, a different type of *sabil* was designated and adapted to offer water to animals (Soliman 2014: 118).

Figure 6. Cistern of Hajj Terbana Mosque (1097AH/1685CE).

The typical *sabil* structure consists of three superimposed integrated units; an underground cistern to store fresh water, a watering room to serve water, and a *kuttab* above to teach Quran and maths to orphans and poor children. In some cases, the upper floor was dedicated to '*Mezamilati*' the person in charge of the *sabil* (Al-Husseini 1988: 9). In comparison to historical documents and reports that testify to a massive amount of *sabils* in Alexandria, the quantity that survive is extremely few. However, eight surviving *sabils* reflect the features of Alexandria *sabils*, and despite *sabils* being attached to various buildings and attributed to different types, they have the same function (**Table 3**).

The mosque is the perfect institution associated with a *sabil* functionally, as spiritual intentions were behind building both of them. As a result, *sabils* attached to mosques are the most splendid, and blend harmoniously in the main architectural composition. Hence, *sabils* attached to the mosques of 'Ali Bey Gueneina (1270AH/1853CE) (**Figure 7**), Desouki al-Kelza (1271AH/1854CE), and Hajj Nazir Agha (1272 AH/1855CE) reflect this pattern.

Attaching a *sabil* to a school or *madrasa* was another habit from the Mamluk period. This design follows the same tradition as those attached to mosques. Despite the modern design of Ratib Pasha school (1300AH/1883CE), a *sabil* was attached (Soliman 2014: 139) and Hajj Hasan Yaqout, a renowned wood merchant, created a unique functional pattern, when he added a *sabil* to his commercial institution, '*wikalat*' (1335AH/1917CE) (**Figure 8**). Nevertheless, attaching a *sabil* to a *wikalat* was not common, because merchants utilize each inch in a *wikalat* to fulfil its commercial function, hence the *sabil* of Hasan Yaqout is a unique example of such charity.

Muslims in Alexandria also attached *sabil* to houses and committed inheritors to maintain them through *waqfs*. The humble *sabil* of the Al Ameen house reflects sincere intentions to provide fresh water as a good deed (Soliman 2014: 118), for instance. Shari'a Court records also indicate other unique *sabils* associated with a garden. One document stipulated filling a basin with

Table 3. Surviving *sabil* in Alexandria.

Name	Location	Date	Architectural Pattern	Structure
Sabil of 'Ali Bey Gueneina Mosque	'Ali Bey Gueneina Street, Bolqatariya Neighbourhood	(1270AH/ 1853CE)	Delta Style	Attached to a mosque
Sabil of Desouki al-Kelza Mosque	Al-Bab al'Akhdar (al-Sikat al-Jadidat) Street	(1271AH/ 1854CE)	Delta Style	Attached to a mosque
Two Sabil of Hajj Nazir Agha Mosque	Al-Bab al-Akhdar (al-Sikat al-Jadidat) Street	(1272 AH/ 1855CE)	Delta Style	Attached to a mosque
Sattuta bint Abdallah	Ras al-Atiyn Street, next to 'Abd al-Rahman bin Hurmiz Mosque	1867CE/ 1284AH	Romei Style	Independent
Sabil of Ratib Pasha School	Ras al-Atiyn Street, next to 'Abd al-Rahman bin Hurmiz Mosque	(1300AH/ 1883CE)	Mixed pattern: Ottoman Rococo (Romei) & Spring (Çeşme)	Attached to School
Sabil and Kuttab al-Khouly	Qabou al-Mallah Street, Bolqatariya Neighbourhood	(c. 13th c. AH/ 19c. CE)	Delta Style	Independent
Sabil Al Ameen	Gomrouk Street	(c. 13th c. AH/ 19c. CE)	Romei Style	Attached to house
Sabil of the *Wikalat* of Hasan Yaqout	Al-Bab al'Akhdar (al-Sikat al-Jadidat) Street, in front of Hajj Nazir Agha Mosque	(1335AH/ 1917CE)	Water Spring (Çeşme)	Attached to *Wakala*

Figure 7. Delta pattern at *sabil* of 'Ali Bey Gueneina Mosque (1270AH/1853CE).

Figure 8. *Sabil* of Hajj Hasan Yaqout Wikalat (1335AH/1917CE): a unique functional pattern attached to a commercial structure.

fresh water three times a day, adding to filling another two *sabils* nearby. This pattern was also mentioned in another document referring to a *sabil* associated with a garden that was supplied with fresh water driven from a waterwheel in the garden through a basin. Unfortunately, none of the garden *sabils* have survived, but it remains in the community's consciousness (Soliman 2014: 140).

The sabils in Alexandria were of three main types: i) Delta style or local Ottoman, ii) Romei or Ottoman Rococo, and iii) Massasa (Çeşme). The Delta style was widespread in the Delta region during the Ottoman period and common attributes characterize all its functional patterns. Most of the surviving *sabil* of Alexandria are attributed to the Delta style, such as the *sabil* of 'Ali Bey Gueneina Mosque, and the two *sabils* of Hajj Nazir Agha Mosque. Common architectural attributes included using fired bricks in decorating the entrance and facade, and arcade. Several types of arches were used, but the triple arch was common to cover main gates and the façade recess, crowned with ornamented cresting. Plain wooden beams covered the internal space of the *sabil*, while limestone tiles paved the floor. The Rococo style influenced Ottoman architecture and art in the 18th Century, and a new harmonized style was innovated, Romei (Soliman 2009: 132). Mohamed Ali, his ancestors, and the elite favoured the Romei style and spread it through Egypt during the 19th century. It is distinguished by elegant curved lines instead of straight lines in the typical Ottoman style (Soliman 2014: 144)

The creation of a simple type of *sabil* began in Anatolia with the Seljuks in the 10th century with Çeşme, which means hot spring, literally. In the beginning, Çeşme were constructed with a pointed arched recess in their façades. A marble plate ornamented with engraved decoration or calligraphy was fixed in the span, while water was poured from a tap to a basin. Çeşme were often attached to mosques and *madrasas* and supplied with water through surface tanks (Negm 2002: 220).

Çeşme when relocated to Egypt were known as 'Hajar Massasa' or 'Sabil Massasa', and although the main design features were preserved, the shape was modified to suit Egypt's different environment and usage. Taking water from a Massasa (sucker) was via a metal nozzle fixed in a marble plate on the façade, allowing passersby to suckle water by mouth, directly (Abdelhafeez 2005: 31). The *sabil* of Rateb Pasha School is an ideal example of Romei style in Alexandria, where two nozzles are installed in the edges of a white marble façade (**Figure 9**). While the *Sabil* Hasan Yaqout had four nozzles. However, *Sabil* Al Ameen still preserves the Çeşme traditions represented in marble plate, basin, and metal nozzles (Soliman 2009: 144).

Figure 9. Ottoman Rococo (Romei) and Spring /(Çeşme) patterns in *sabil* of Rateb Pasha School (1300AH/1883CE).

Historical Creativity of Water Technology

Alexandria presented an integrated water process. Alexandria derived water from storing the Nile flood in cisterns annually. Water techniques are aligned in a specific process: supply, distribution, and filtration.

Water resources and supply system

The cisterns of Alexandria were supplied with fresh water through two means: by conduits that derived water from the Canal of Alexandria and harvesting winter rainfall. Historical sources describe the water infrastructure. Hirtius (d. 90 BCE), for example emphasized how conduits reached to wells inside every elite house, while the common people sought to get water from the canal by themselves (Al-Sharqawi: 107). The Andalusian geographer al-Zuhri highlighted continuity of the same system in the 12th century, which survived until the 19th century. (Hammad 1998: 289)

The standard depth of the cisterns in Alexandria facilitated the filling process, so the usable water stayed at the top of the cisterns. Archaeologically, waterwheels used to extract water from cisterns in the 17th century have been found (Mckenzie 2007: 220). Nevertheless, the conduits did not supply all the cisterns of Alexandria. Therefore, waterwheels were installed on nearby streams to pump water to the cisterns, alternatively the cisterns were filled with huge water bladders carried on camels and donkeys. (Al-Falaki 1967: 89). Urban decline in isolated cistern areas was the reason behind this complicated dual-filling system.

Winter rainfall harvesting

Siltation of the canal in winter caused water scarcity in Alexandria. Nasir Khusraw highlighted in the 11th century the use of rainfall as a fresh water source in Alexandria. (Khusraw 1993: 99) This does not imply that Alexandrians relied on rainwater as a main water supply but as a secondary source because of the rainfall limitations in Alexandria. Where rain in January and February is estimated at 150-200mm. (Hurst & Phillips 1931: 53).

Rainwater was collected in tiny cisterns beneath houses and mosques. Alexandrian architects in the medieval period revived a historical technique to collect rainwater that fell on rooftops, as recorded in the Terbana Mosque. The technique consisted of installing symmetrical pottery pipes 35cm in length and 15cm

Figure 10. Rainfall harvesting technique associating with a cistern under Hajj Terbana Mosque (1097AH/1685CE).

in diameter to each other vertically, aligned with the building corners (**Figure 10**). The reason behind the pipe being made of separate parts was to enable masons to bond it with each course and to make maintenance easier. The pipe linked Terbana mosque roof allowed the rainwater to go down to the cistern smoothly. The architect considered the inclination of the roof to let rainwater run towards the pipe inlet. Archaeological discoveries in the Kom al-Dekka area also indicated that the rainfall pipe technique was utilised in Alexandria during the Roman period (Mckenzie 2007: 220).

Multiple water mechanisms

Waterwheel - 'Sāqiyah'

Waterwheels were utilized widely in the cisterns of Alexandria. The Napoleonic campaign estimated that the ruler of al-Buhira province was committed to providing 72 units powered by oxen and horses, annually. Two designs were used in Alexandria: stream waterwheel and overshoot waterwheel.

The stream waterwheel was the most commonly used type of waterwheel designed by the ancient Greeks and Romans as it is the simplest, cheapest and easiest type of wheel to construct. This type was used to raise running water from a conduit to a Sultani cistern. Stream waterwheels were usually installed on a rectangular well above the conduit and outside the cistern structure. Napoleonic scholars attributed the huge amount of pottery sherds spread everywhere in Alexandria to the broken pottery buckets, which were installed in stream waterwheels to raise water (Description de l'Egypte 2003: 356).

Overshoot waterwheel: This design comprised an array of buckets joined together with a thick rope and suspended on a vertical gear axle rotated on a horizontal axle fixed on both sides of the well and was operated by animals rather than water flow. Another gear axle connected to the vertical one, horizontally powered by animals to operate water extraction process in the overshoot waterwheel. An overshoot waterwheel installed on a central well opened in most Sultani cisterns and some Baladi cisterns, according to the function and consumption, and availability of required free land (Lane 1991: 337). A supervisor was employed to operate and maintain the waterwheel. His responsibilities included fixing buckets, providing rope and other supplies, and feeding the traction animals, and this profession accompanied waterwheels whether linked to Sultani or Baladi cisterns (Azab 2011: 112).

The original names of some neighbourhoods in downtown Alexandria reflect the existence of waterwheels. For instance, the waterwheel that was located in the backyard of Al-Qaid Gawhar Street (Combe 1943: 61).

Shaduf

A *shaduf* consists of two pillars of wood, clay, or reed, about 150cm high and spaced about 100cm apart. A horizontal beam of wood extends above the upper tips of the two pillars, from which a thin tree branch crane hangs. A counterweight is attached to the internal tip. A round bowl was suspended at the other tip, made of ropes or a collar, and stuffed with wool or leather. The *shaduf* was operated by raising water to a height of about 250cm in a hollow basin to receive the water and ensure its flow. It took two men to move the two-lever shafts, which was tedious work (Lane 1991: 337).

Buckets and rope

The operators in cramped spaces inside cisterns and *sabils* used a simple bucket and rope method to lift water directly from a shaft inside the structure. This method was utilized in cisterns of houses, *sabil*, and fortifications in medieval Alexandria.

Archimedes' screw - Tambour

During Archimedes' journey to Egypt, he invented a machine of wood to raise water from drydocking and canals for irrigation, attributed to his name and known in Egypt as a *tambour* (Lane 1917: 337). The *tambour* consists of a loop inside a cylinder. The lower end of the loop fixed in a pillar, while a steering hand installed in the upper tip on two pillars with 30° angle. The shaduf was operated by getting the lower tip down into the water (Empereur 1998: 133).

Hydro-processing methods

Water scarcity in Alexandria and subsurface brackish water affected the water quality. Furthermore, silty sediments decreased the amount of water flowing smoothly through the water network. As a result, purification methods were highly regarded. To prevent sediments and impurities from entering the conduits, iron nets were set firmly. Additionally, culverts placed at the conduit mouths pushed silt out (Al-Shayyal 1967: 83; Empereur 1998: 133).

Explorers observed how the Nile flooding impacted water quality. Water was usually contaminated with silt and so undrinkable. Therefore, the people of Alexandria should wait until the water was clear. Meanwhile, they drank stored water from the cisterns from the previous year. Villamont from Brittany, who visited Alexandria in 1590, reported that the new flood water that arrived in Alexandria caused fever and dysentery. As a result, people were cautious not to drink cistern water until November, when the new flood water became cleaner (Empereur 1998: 134).

Krystof Harant, a Czech nobleman who visited Alexandria in 1598, criticized the weakness that led to a plague. The weakness was the silty water that accumulated in the cistern bottoms, causing a smell and an unhygienic environment. Unless people cleaned the cistern of rubbish and silt before the annual filling, the new fresh water was contaminated, causing infection and fever (Empereur 1998: 136). Alexandrians were also skilful at water purification methods of varying effectiveness. The Coptic calendar recommended heating water commencing on 15th June every year, while Arab historians and European explorers favoured the use of strainers. They also used other effective substances that make water safe to drink, adding to improving the taste, such as chalk and vinegar, as well as fruit kernels, which likely purify turbid water (Raymond 1974: 87).

As a result of Alexandrian coexistence with water that was renewed annually, they realized the diseases that might cause death if they consumed this water directly without purification. The Alexandrians adopted several methods to purify water. Al-Maqrizi mentioned some methods, including the filtration of unfavoured substances suspended in water using chalk, types of clay, and apricot kernels. Another method is to distil water in ceramic, pottery, or leather vessels after heating and letting it cool (Ramadan 2006: 85).

Administrative and Management Organisations

Successive governments in Islamic Alexandria committed to monitoring and maintaining the water system. A non-governmental administrative system, similar to the modern syndicate system, was arranged into unions that shared responsibilities with the government and guaranteed the validity of their members ability to practice water-related professions.

Governance of water management

Cisterns were the most significant element in the water system of Alexandria. Paying attention to cisterns was one of the priorities of the successive dynasties that ruled Egypt from digging the earliest cistern during the Ptolemaic period until the 20th century, constructing, restoring, or rebuilding was the highest priority. Muslim jurists obliged the government to protect and facilitate water as a fundamental human right. They even required the government to preserve and clean public waterways and bridges. However, if the water resource is held by a specific union, they should preserve it (Azab 2011: 17).

Islamic Water legislation grew rapidly to the point where jurisprudential terms of water, such as the right to share water, the right to conduct water, and the right to drink, evolved. Books of architectural jurisprudence are no longer devoid of chapters related to water issues. The significance of water concerns in Islamic society has grown to such an extent that cases about water disputes or endowments can now be found in the records of Shari'a courts (Azab 2011: 18).

Water management in Islamic Alexandria was organized by several administrative organizations; the most significant of which was the market supervisor, *Mūḥtāsīb*. *Mūḥtāsīb* duties included inspection of the craftsmen unions associated with the construction, cleaning, maintaining, and filling of cisterns. Ibn Khaldun stated that *Hisbah* was a religious appointment that falls under the principle of enjoining what is legitimate and forbidding what is evil. This is a duty imposed on the Muslim leader, who appoints those he believes appropriate for the *Mūḥtāsīb* position and his assistants (Ibn Khaldūn 2003: 611). The *Mūḥtāsīb* ought to have a reputation for knowledge and wisdom. In recognition of his work in the judiciary, the *Mūḥtāsīb* was selected to serve as one of the judges in the early Islamic period (Salem 1959: 222).

Non-Governmental Organizations role of water management

The construction of cisterns and water supply was associated with various crafts, such as carpenters, builders, waterers, etc. Labour unions called *Twaif al-Hiraf* were created by the craftsmen (Soliman 2014: 79).

Pre-annual flood, preparedness was begun. Annual maintenance was performed prior to the flood to regulate the new water and mitigate its destructive impact. Alexandria Shari'a Court documents describe the Day of the Nile Inundation, which was proven officially by the arrival of water into the Canal of Alexandria in a popular celebration headed by the Effendi judge of Alexandria. A crowd of public attendees accompanied the Effendi judge to witness the event, including elites and employees, as well as carpenters and masons, who were responsible for maintaining the Sultani cisterns. After inspecting the waterwheels and cisterns to verify their safety and fullness, the Effendi judge of Alexandria and attendees testify in a report signed by each of them.

The official procedure for the annual water supply is described in a document of the Shari'a Court of Alexandria, dated 1053AH/1625CE. The document stated that the Emir of the Sharif Sultani Flag; Mamai Bey, Emir of the Beheira Province, was the supervisor of the Khalij al-Nasiri—the Canal of Alexandria. Mamai

Table 4. Cistern statistics extracted from Sharia Court records.

Year	Total Count	Valid	Invalid
1033AH (1623CE)	66	66	-
1046AH (1636CE)	82	82	-
1053AH (1649CE)	85	84	1
1086AH (1675CE)	116	116	-
1213AH (1798CE)	308	207	101

Bek was the chief of Emir Mohamed Jawish, the person in charge of maintaining the Sultani waterwheels in Alexandria. In addition, the document identified other responsibilities for the waterwheel supervisor, including blocking canals to keep water, cleaning conduits and streams, restoring and strengthening bridges, bringing required bulls, and testing the Sultani waterwheels by operating them until the Sultani cisterns were full (**Table 4**) (Shari'a Records 1053AH; Shari'a Records 1099AH: 188).

These manifestations continued until the French campaign in 1798. The *Description de l'Égypte* highlighted the same process when some conduits' outlets were plugged. Therefore, when the Nile level rose sufficiently, the Canal of Alexandria and the conduits were opened. The barrier was restored after the conduits filled the cisterns, and water continued to flow towards the sea (Description de l'Egypte 2003: 226).

Cistern masons' union

The Cistern mason's union was among the most important architectural unions. They were responsible for constructing and renovating the Sultani cisterns, as well as cleaning the canals and conduits (Mahmoud 2008: 97). Cistern masons' tasks began before the Nile flood, annually. The Alexandria Judge had to forward orders from the central government in Cairo to the Alexandria *Diwan al-Gamarik* 'Customs Office' so that the head of the union could receive the orders for implementation. The Customs Office covered the financial cost of the cistern masons, adding to the two oxen paid annually by the Emir of al-Buhaira, the Sanjak.

The responsibilities of cistern masons were limited to building and restoring cistern wells. Moreover, carry out the necessary restoration inside cisterns so that water does not leak when it is full in addition to building new cisterns (Mahmoud 2008: 98-99).

Waterwheels carpenters' union

Waterwheels carpenters were entrusted with the manufacture and restoration of Sultani waterwheels that move water up from the canals to the Sultani cisterns. This union worked under the supervision of those responsible for leasing and building waterwheels, whose commitment was granted by the Emir of the Buhira Province. The fees for this union were also disbursed from the Alexandria Customs Office. Other unions worked within this union, such as sawmills and woodcutters, who cut the wood needed to manufacture the wheels and its parts.

Records estimated the number of waterwheel carpenters was 179, both senior and junior carpenters. The wages of the senior carpenter amounted to 50 *Nisf*, compared to 25 *Nisf* for the junior carpenter. Additionally, water wheels carpenters were giving a herd of bulls to assist with transport waterwheels and timber (Soliman 2014: 81).

Sewer worker Union – 'Bayarin'

The Bayara duties were to drain Sultani cisterns of stagnant water and sediments, as well as to clean leftover waste that remained after the annual maintenance (Soliman 2014: 81). The Bayarin union continued its assigned duty of maintaining cisterns until the late 19th century, when cisterns were abandoned as a means of storing water (Abdelhafeez 2007: 198).

Watercarriers Union – 'Ṭāʾīfī al-Sāqāyin'

The commonest union involved in water management in Alexandria, as well as in other mediaeval Islamic cities. The Watercarrier Union was a group of men responsible for transporting water from waterways to fill Sultani and Baladi cisterns using water bladders on the backs of camels or donkeys. Water carriers worked often during the Nile flood, seasonally.

The books of jurisprudence and *Hisbah* outlined the stipulation of practicing the water-carrying profession, which were determined by the *Mūḥtāsīb*. The stipulations concern public health, including diseases related to water dirt. A section of the terms concerns the filling process and the quality of water to resist manipulations. The *Saqāʾ* was mandated to fill water bladders in the middle of the river to areas of dirt on the banks. The *Saqāʾ* should be a trustful person who avoids mixing fresh and contaminated water. Furthermore, the *Saqāʾ* should avoid filling at night because it is difficult to be cautious, thus Saqāʾ should take extra precautions. Other rules guaranteed the safety of water-transporting tools.

Fresh water bladders should not be used directly so that the taste, colour, or smell of the water does not change due to the effect of tanning. In addition, the water bladder should have a visible, dense cover spanning the entire water bladder to prevent harming passersby clothing. Moreover, the water bladder must also be free of holes because it causes a lack of water, which was considered dishonest. Nevertheless, further rules were imposed regarding the etiquette of stroll on the road, entering homes, and dressing appropriately (Al-Husseini 1988; Azab: 2011).

The *Saqāʾ* profession survived in Alexandria until the early 20th century. According to Ali Pasha Mubarak, the number of unions in Alexandria was estimated at 142, with a total of 26,900 members, which is equivalent to triple the population of Alexandria during Mohamed Ali Pasha's reign. Ali Mubarak identified two separate watercarrier unions, even though both of them introduced the same service. One of which included 424 persons specializing in transporting water to public facilities such as cisterns and *sabil*, while 55 water carriers aligned in the union that delivered water to houses (Mubarak 1987: 209). E.W. Lane reported a separate group called cup-water carriers, serving water to passersby in copper bowls for charge (Lane 1917: 344).

Al-Muzamilati

Serving the *sabil* water to passersby was a job undertaken by a person called the *Al-Muzamilati*. In addition, the *Al-Muzamilati* was responsible for filling the *sabil* cistern, adding rose water to the drinking basins, cleaning the *sabil*, and sprinkling water in front of it. The *Al-Muzamilati* also guarded water utensils and was in charge of lighting the Sabil. They had a room designated for storing water utensils (Ibn Wāṣil 1977: 317).

Al-Mazmalati was demanded to fulfil the health requirements necessary to obtain this profession; this included having no skin and infectious diseases, particularly leprosy. The *Al-Muzamilati* should also be religious, facilitating water for passersby and treating them with good manners. In addition, there was an overall requirement of adhering to honesty in dealing with the substance of life, water. (Soliman 2014: 138).

Conclusions: The Suitability of Historical Solutions to Tackle Contemporary Complications

Investigation of historical water techniques in Islamic Alexandria could address current water-related problems. A deeper comprehension of the building materials of surviving hydraulic architecture adds value to modern conceptions of architecture and considering environmental dimensions.

Several water concerns confront the globe today on multiple fronts. Population growth and development have raised water consumption, while the world's water supply has become insufficient. Climate change adds challenges to the water future, causing droughts. Increasing water consumption requires unconventional ideas to tackle successive problems. Historical water techniques in Islamic Alexandria demonstrate integrated, accumulated knowledge and inspire new concepts that generate creative methods that may help solve contemporary water problems.

The location of Alexandria, which is distant from sustainable fresh water sources, inspired an urban rainwater harvesting system. Alexandria, as a coastal rainy city, receives a moderate amount of rainfall, allowing it to store rainfall on buildings in underground cisterns. Rainwater harvesting has been consumed historically in times of drought. The implications of adapting the historical rainwater harvesting system from a sustainable perspective introduce an efficient dual solution. The concept of the proposed adapted technique is to collect fallen rainwater above buildings and forward it to subterranean ducts assembled in public tank stations. That system also keeps the streets dry by reducing the amount of water that drains into them.

The shortage of clean water is a serious issue that threatens human health. Reviving traditional water purification techniques that rely on pottery is a significant method. Scientifically, pottery utensils for daily human use, especially concerning cooking and drinking, have been proven to be the healthiest natural means. Replacing chemically manufactured filters with pottery in in-home filter components produces clean water successfully. Consequently, creating modern pottery designs that meet contemporary standards adds multi-dimensional value. The proposed designs would provide healthy products that improve water quality. Job opportunities related to the pottery industry would be created for mass production as well as to preserve it as an intangible heritage value.

Specific criteria categorize the cistern pattern. Function is the most effective measure for identifying the required capacity based on the purpose of consumption. Topographic surface level of cistern location controls the depth, where the higher the surface level, the deeper the cistern and the more levels it has. Soil types in Alexandria imposed digging cisterns in hard rock only or adopting one of the other masonry cistern patterns.

Innovation in the Alexandria water system is inspirable beyond only hydrological treatments; using sustainable natural materials for building improves the water quality and consolidates the structure itself. Natural mixtures were used in constructing and refining water infrastructure in Islamic Alexandria. The utilisation of building materials in cisterns and conduits enabled Alexandrian architects to prevent fresh water leakage into the subsurface layer and surrounding building foundations. Analysing the cistern building materials reveals characteristics compatible with contemporary environmental architecture standards. Plaster (*saruj*) and mortar are the most prominent building materials that can be reproduced in mass production.

Nevertheless, inaccessibility to the cisterns of Alexandria hinders efforts to reveal more relevant information. Whilst the rehabilitation of the cisterns adds value to the tourism industry, which is a source of major national income for Egypt. Moreover, from an adaptive reuse perspective, an integrated project can revive the cisterns as a chain of cultural stops spread over Alexandria. Cultural stops would serve the community, researchers, as well as tourists.

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Chapter 14.
The Potential of Istanbul's Water Heritage for Current and Future Water-Related Challenges

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Introduction

This chapter focuses on water heritage in Istanbul, i.e. the surviving physical artefacts connected to the city's system of water supply and use through the ages and the possible role this heritage can play for current and future challenges related to water supply and use.

The history of the modern metropolis of Istanbul, according to tradition, dates back to the 7th century BCE, when Byzas founded Byzantion. The oldest written sources mentioning a water supply system date back to the 5th century CE (all dates are CE, unless otherwise specified).[1] From these we know that Roman emperor Hadrian (r. 117-138) constructed a gravity-based waterway that supplied the lower part of old Byzantion between the city's first and second hills. The source of this so-called Hadrianic line were springs located at Cebeciköy, at a distance of c. 20km north-west from the lower east end of the peninsula, and further north at the Forest of Belgrade. Freshwater had to be brought in from outside the city because there were too few freshwater sources. That situation has shaped the history of Istanbul's water supply and use until today.

The oldest physical remains of Istanbul's water supply systems date back to the 4th century, from after the foundation of Constantinople by Emperor Constantine (306-337) in 330. Under Emperor Valens (r. 364-378), construction began on a gravity-based system consisting of channels, aqueduct bridges and tunnels that carried water through the landscape from Thrace. The source were springs at Danamandıra and Pınarca at a distance estimated at more than 1000 stades (185km) by Themistius and over 200km by modern researchers.[2] In the 5th century, under the Theodosian dynasty, the waterway was extended to springs at Pazarlı, near Vize. The total length of the water supply system, which became known as the Valens waterway, is estimated to be at least 426km and possibly as much as 564km (Crapper 2020; Ward *et al.*, 2017a and b). This long-distance system had to be adapted over the centuries due to changing conditions, including droughts, hostile attacks, and fluctuating population numbers. A major event was the siege of the city by the Avars in 626 when the Valens line was cut off. Until the restoration under Emperor Constantine V (r. 741-775) in 766, the city must have been supplied with water only via the Hadrianic line.

Istanbul only became Islamic after the conquest of the city in 1453 by the Ottoman Turks. The Byzantine water supply system, which had largely fallen out of use, was partly revitalized and restored by Sultan Mehmed II (r. 1451-1481). The restoration mainly involved the revitalization of a part of the Hadrianic waterway, which became known as the *Kırkçeşme* waterway, named after a public fountain called *Kırkçeşme* (forty fountains). The *Kırkçeşme* water supply line was further expanded by the architect Sinan between 1554 and 1563 and it became the most extensive Ottoman water supply system. This system too underwent modifications over the centuries such as the restoration due to floods that occurred shortly after the completion of the waterway in 1563 (Çeçen, 1996b: 43; Karakaş 2021: 308).

Research on Istanbul's water heritage has focused on the history, survey and reconstruction of Istanbul's historical water supply systems. The basis for research on both the Roman-Byzantine and Ottoman water supply systems, especially that of the architect Sinan, was laid by Kazım Çeçen. It was also Çeçen who rightly claimed that when the Roman-Byzantine waterway was completed in the 5th century it was the 'the longest

[1] The aqueduct of Hadrian is first mentioned in a law issued 440 CE by emperors Theodosius II (r. 408-450) and Valentinian III (r. 425-455), *Corpus Iuris Civilis, Codex Justinianus*, 11.43.6, Frier 2016: 2718-2721. Crow *et al.* 2008, 10 (Appendix I: 227) mistakenly refer to 11.42.6 instead of 11.43.6 and to Theodosius I and Valentinian II as the emperors who issued the law. The address to the Praetorian Prefect Cyrus indicates that the emperors that promulgated this law were in fact Theodosius II and Valentinian III.

[2] Themistius, *Oratio* XIII. 167c-168c. in Crow *et al.* 2008: 224. Distance of the springs at Danamandıra and Pınarca estimated 250 km according to Crapper 2020.

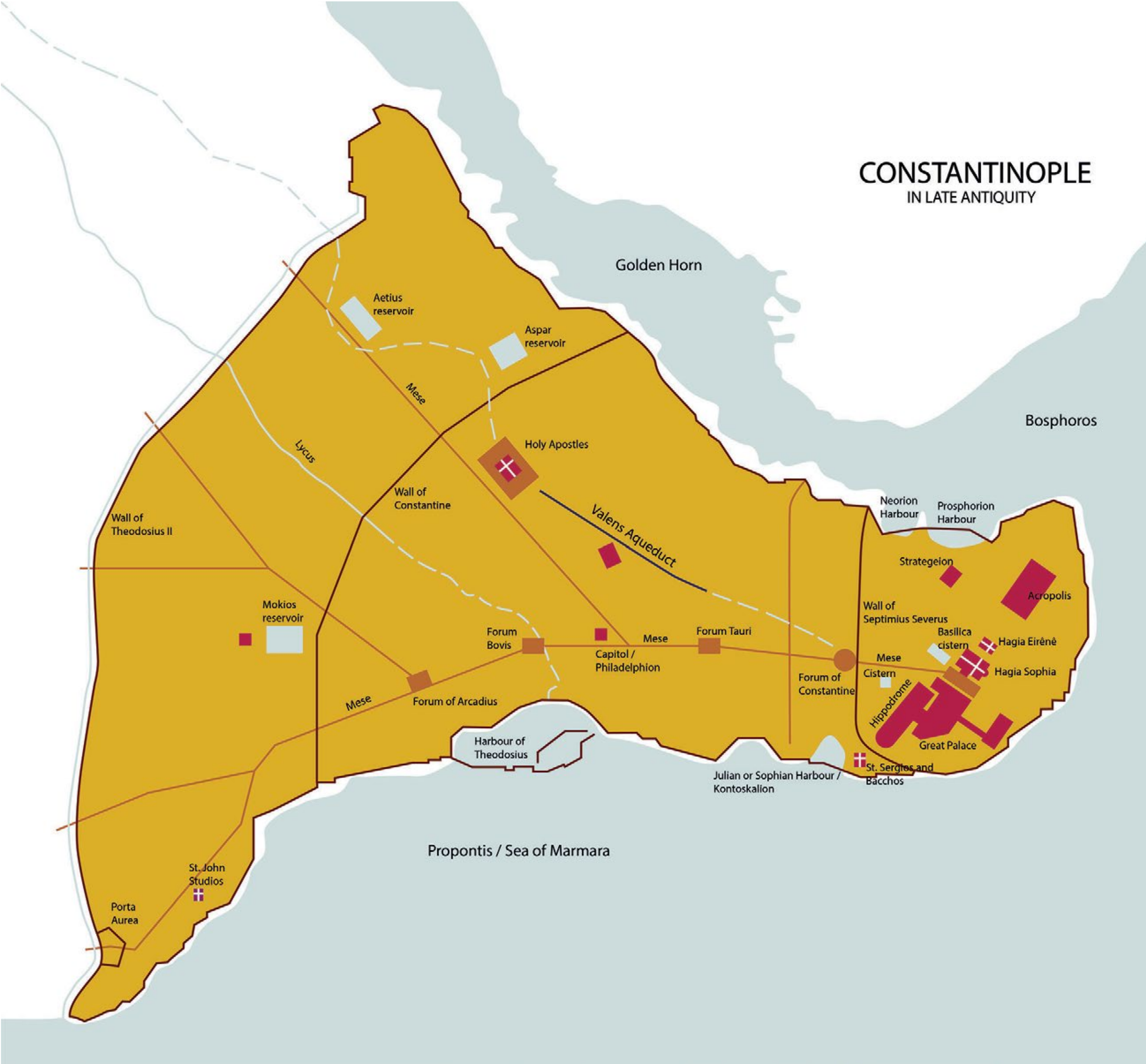

Figure 1. Plan of Constantinople in Late Antiquity (© Studio Hartebeest, 2021, adapted by Mariëtte Verhoeven).

Roman water supply' (Çeçen, 1996b). James Crow and others further surveyed this long-distance system and published the results in *The Water Supply of Byzantine Constantinople* (2008) and several journal articles (Çeçen, 1996a).

Instead of focusing on the history and reconstruction of Istanbul's historical water systems, but building on it, in this chapter I concentrate on the past in the present, i.e. on what is preserved of the historical water systems in the current city. Therefore, I will first give a brief overview of the most important surviving remnants of Istanbul's water supply systems through the ages until the foundation of the Republic of Turkey in 1923. This concerns parts of the waterways described above, i.e. the various systems consisting of channels, bridges and tunnels that supplied the city with water, and installations for water storage and use that were directly or indirectly connected to those systems. This overview is not in any way meant to be exhaustive but aims to give an idea of the diversity of water heritage from Istanbul's multi-layered past still visibly testifying to the efforts made to set up and manage the city's freshwater supply. Therefore, I also limit myself to the water heritage located in the part of the city now known as the historic peninsula (**Figure 1**) i.e. the area within the so-called Theodosian wall dating back to the 5th century where the city's multi-layered history is most tangibly present.[3] As this is also the touristic heart

[3] Not part of the freshwater supply system and therefore outside the scope of this chapter are the archaeological remains of the Harbour of Eleutherios, originally known as the Harbour of Theodosius, where the Lycus river emptied into a bay. At this site, now called *Yeni Kapı*, between 2004 and 2013 the remains of 37 shipwrecks, among others,

of the city, it is here where both residents and tourists engage most with the water heritage present. In the last part I will address the main topic of this chapter by answering the question of what role the visible remains of the past can play for current and future sustainable water use and management challenges. To this end, I present a number of concrete proposals and initiatives.

The Past in the Present

Aqueducts

The most monumental remains of Istanbul's historical waterways are the aqueduct bridges. The only aqueduct bridge whose remains survive on the historic peninsula is the so-called Valens Aqueduct (Turkish name: *Bozdoğan Kemeri*), a 971m long arched aqueduct bridge between the fourth and third hills of the city (**Figure 2**). It was part of the Valens waterway whose other surviving, ruinous, remains are largely in difficult to access forested areas in Thrace.[4] The aqueduct as it stands today dates back to the year 373, when under Emperor Valens (r. 364-378) the prefect Clearchus brought 'the long-prayed for water' to the city (Jerome, Chronicle (373) in Crow *et al.* 2008: 225). The aqueduct shows traces of its use in Byzantine times such as a *Christogram* on one of the arches' key stones. From the Ottoman period the lines of Ottoman ceramic pipes survive as well as an inscription mentioning the renewal of five arches under Sultan Mustafa II (r. 1695-1703).

Figure 2. Valens Aqueduct (*Bozdoğan Kemeri*), founded in 373 CE, situation in 2024 (photo. Mariëtte Verhoeven).

Beyond the scope of this article are the aqueducts on the outskirts of the modern metropolis dating from the Ottoman era such as the *Mağlova Kemeri* (**Figure 3**), the *Uzunkemer* and the *Güzelcekemer*, all by the architect Sinan and all belonging to the *Kırkçeşme* waterway. I want to mention them here because of their good state of preservation and visible presence.

Figure 3. *Mağlova Kemeri* (Mağlova Aqueduct), 16th century CE, situation in 2021 (photo. Mariëtte Verhoeven).

Reservoirs and Cisterns

More than 200 reservoirs and cisterns from Byzantine times which stored water brought in by the waterways are attested in literary sources and/or have been archaeologically confirmed.[5] Within the Theodosian walls the 'footprint', i.e. (parts of) the enclosure wall, of the large open reservoirs of Aetius, Aspar, and Mokios remain (Crow *et al.* 2008: 128-132). The 5th century Aetius and Aspar reservoirs were located on the fifth hill of the city and were supplied with water from the Valens waterway. The water collected here likely was used for agricultural purposes but given the capacity -

were found during work to construct the *Marmaray* metro line, which will eventually be exhibited in a museum planned at the site. viewed 15 September 2024, <https://nauticalarch.org/projects/yenikapi-byzantine-shipwrecks-project/>

[4] The aqueduct extends 971m in length but is interrupted in the section between the Şehzade mosque and the Vezneciler dormitory for girls. See Crow *et al.* 2008: 25-108 for the survey of the remains of the Valens line in Thrace.

[5] Ward 2017b. List of 161 reservoirs and cisterns with literature references in Crow *et al.* 2008: 145-155, and 158 in Altuğ 2013. Corpus of cisterns first published by Forchheimer and Strzygowski 1893. Plans of reservoir and cisterns mentioned in this paragraph in Crow *et al.* 2008: 215- 216.

in total the three open reservoirs could have held more than 600,000m³ of water - they probably also served as a strategic reserve in times of water shortage. The Aetius reservoir (244 x 85 x 13-15m) is now a football stadium and that of Aspar (152 x 152 x 10-11m) a park with sports fields. The basin of the Aspar reservoir was still used as a *bostan*, for urban gardening, into the 20th century. In the north corner the remains of a cylindrical tower (late 10th century) that was added to reduce the pressure of water exiting the reservoir can still be seen. The Mokios reservoir (170 x 147 x 12m), probably built under Emperor Anastasius (r. 491-518), was located on the city's seventh hill, also known as Xerolophos ('dry hill'). Water possibly came from a branch of the Valens line or from the Halkalı freshwater springs, located west of the city. Since the early 21st century, the former Mokios reservoir has been in use as a public park.

Figure 4. Basilica Cistern (*Yerebatan Sarayı*), 6th century CE, situation in 2022 (photo. Mariëtte Verhoeven).

Freshwater (and possibly rainwater) was also collected in numerous underground cisterns (Crow *et al.* 2008: 137-143). There is almost no evidence for the methods of supplying water to and extracting water from the cisterns. The covered cisterns were brick-built, divided into bays, with arches supported by columns. The capitals are in most cases spolia which makes dating of the cisterns difficult. About a third of the underground cisterns date from the 4th to 7th centuries. The largest are located in the oldest part of the city, in the area of the first and second hills. Many of the cisterns served as substructures for buildings. Very recently, the remains of a Byzantine cistern were recovered under the *Çinili Hammam* (see below).

Figure 5. Theodosius Cistern (*Şerefiye Sarnıcı*), 5th century CE?, situation in 2022 (photo. Mariëtte Verhoeven).

Some of the underground cisterns are well preserved and open to the public. The most famous is the recently restored Basilica Cistern (*Yerebatan Sarayı*) (**Figure 4**), which got its water from the Hadrianic line. The cistern is the largest underground cistern measuring 138 x 65m. It is supported by 336 columns and dates back to the time of Emperor Justinian (r. 527-565). Other restored and accessible cisterns are the Thousand and One Columns Cistern (*Binbirdirek Sarnıcı*) (5th-6th century), also called 'Cistern of Philoxenos', measuring 64 x 56m and supported by 224 columns, and the Theodosius Cistern (*Şerefiye Sarnıcı*) (5th century?), measuring 24 x 40m with 32 supporting columns (**Figure 5**). The latter serves as a stage for a commercial light and sound show telling the history of the city.

The *Unkapanı* or *Zeyrek* Cistern is located near the Valens Aqueduct and was built against the city's fourth hill on which stands the former Pantocrator monastery, now the Zeyrek mosque. The dating of the cistern is uncertain. Possibly the cistern was part of the construction of the Pantecrator complex in the 12th century but may also date back to the 6th century. The cistern measures c. 18 x 55m, with 2 rows of 11 columns and piers supporting the vaults in the interior. The cistern stands out because the buttressed exposed outer walls with niches were and are still visible, nowadays along the Atatürk Boulevard. The interior has been restored in recent years but is not open to visitors.

Public Baths

The existence of public baths in Constantinople dates back to the time of Emperor Septimius Severus (r. 193-211), who had a bathing complex (*thermae*) built next to the Hippodrome, which was completed by Emperor Constantine in 330. These so-called baths of Zeuxippos, like the Baths of Achilles (late 4th century) on the *Strategion,* received their water via the Hadrianic waterway. Simultaneously with the construction of the Valens waterway, two baths were also built,

Figure 6. Remains of Roman bath between the Kalenderhane Mosque and the Valens Aqueduct (photo. Mariëtte Verhoeven).

the *Anastasianae* and the *Carosianae*, named after the daughters of Emperor Valens (Mundell Mango 2015; Crow *et al.* 2008: 10-11).

The only still visible archaeological remains of a Roman bath are the foundations of a small bath (*balneum*) (**Figure 6**) dating back to around the year 400 located directly next to the east end of the Valens Aqueduct. The remains were excavated and surveyed in the 1960s (Striker and Kuban 1997; 2007). The bath consisted of a trefoil room, a circular room with three projecting semi-circular niches, and a circular room with a projecting rectangular niche (Striker and Kuban 1997: 31). To the west of this sequence of rooms was a large, open hemicycle with an elliptical room to the south of it. To the right of the remains of the bath stands the Kalenderhane Mosque, a former Byzantine church called Theotokos Kyriotissa that was transformed into a mosque after the conquest of Constantinople by the Ottoman Turks. Its complex building history dates back to the 6th century when a church was built against and partly over the rooms of the bath complex.[6]

The tradition of bathing as a public and community activity continued in Ottoman times. The oldest surviving public bath or hammam that is still in use is the *Çemberlitaş* Hammam, located at the Divan Yolu, the former Mese, and opposite the Column of Constantine, known as *Çemberlitaş* in Turkish. It was established as part of a *waqf,* a charitable endowment and was completed in 1584.

The *Bayezid II* Hammam was a public bath house belonging to the mosque complex of sultan Bayezid II (r. 1481-1512). It was founded in 1507-1508 as a double bath, with separate spaces for both men and women, by Gülbahar Hatun, sultan Bayezid's wife. Because of its size and monumentality, the hammam was also called *Hamam-ı Kebir* (Great Bath). After the hammam became the property of İstanbul University in 2000, the building was restored and put into use in 2015 as a museum where visitors are informed about the history of Ottoman Turkish bathing culture (**Figure 7**). In the former hot, cold and changing rooms, objects from Ottoman Turkish bathing culture are displayed, as well as archaeological remains found in the surrounding area including those from former Byzantine churches.

Another Ottoman public bath that should be mentioned here is the recently restored *Çinili* Hammam (Tiled Bath), located in the Zeyrek district, one of the 'Historic Areas of Istanbul' inscribed in the UNESCO World Heritage List in 1985 (Şengözer and Özbay 2024). The double hammam was built between 1530-1540 by the architect Sinan by order of Barbaros Hayreddin Pasha,

[6] For the possible reuse of the hydraulic infrastructure of the bath for a fountain located 15m south of the church and contemporaneous with it see Blid Kullberg 2016.

Figure 7. *Bayezid II* Hammam, 1507-1508, interior, situation in 2024 (photo. Mariëtte Verhoeven).

the Grand Admiral of the Ottoman Navy. The interior of the hammam was lavishly decorated with tiles from Iznik, which also gave it its name. In the 18th century the *Çinili* Hammam was used as military stables. A certain Ali Bey, the first private owner of the hammam, undertook extensive restorations between 1833-1850 but this could not prevent that in the second half of the 19th century under one of the subsequent private owners a large part of the hammam's tiles were sold by an antique dealer in Paris. After the dilapidated hammam was acquired by a private company in 2010 an extensive restoration project was initiated during which the remains of a Byzantine cistern on which the hammam was built were found. On the walls of the cistern plaster incised graffiti depicting galleys were discovered which are as yet of unknown date.

Artifacts found during the excavation and restoration project date from the early Byzantine period to the 20th century. They include terracotta vessels, oil lamps, glass bottles, coins and around three thousand 16th-century blue and white Iznik tile fragments. A selection of these artifacts are on display in the museum which is built as an annex to the hammam (**Figure 8**). Here, the history of the Iznik tile decoration is also explained including a digital reconstruction of the different tile patterns. The museum has also a section with objects pertaining to Ottoman Turkish bathing culture with a unique collection of *nalıns*, special hammam slippers. When renovating the hammam, it was decided not

Figure 8. *Çinili* Hammam, 1530-1540, fragments of Iznik tiles displayed in the museum part of the hammam, situation in 2024 (photo. Mariëtte Verhoeven).

to reuse the separate fragments found but only to preserve and display the tiles that survived in their original location in the interior. The restored hammam functions as a luxury double bath house for men and women with treatments at commercial prices.

Distribution Chambers and Water Towers

As already mentioned the historical waterways used gravity to lead water over great distances into the city. For the Roman period, the system for distributing water within the city is documented both in writing and archaeologically for cities such as Rome, Ostia, Pompeii and Ephesus (Crow *et al.* 2018: 109). Components of this system included *castella divisorium* or *castellum aquae* (water distribution chambers), water towers (with elevated containers to balance the water pressure), private tanks and private lead pipes to deliver water to public baths and basins, fountains, and houses. The water towers, of which fourteen are archaeological identified in Pompeï, functioned as a series of linked siphons. For Roman-Byzantine Constantinople, however, neither the written or archaeological record testify of the existence of elevated water containers although it is unlikely that pipelines run directly from the main channel of the Valens waterway to installations such as the public baths and fountains (Kessener 2017: 86).

While there is no evidence for the existence of distribution chambers or water towers from the Roman-Byzantine period, the remains of both type of installations survived from the Ottoman period. The *Kırkçeşme* waterway ended at the *Savaklar* or *Eğrikapı maksemi*, located just outside the wall of the historic peninsula. A *maksem* or *taksim* is a water distribution chamber and at the *Savaklar maksemi* the water of the Kırkçeşme waterway was divided into two branches transmitting water to lower regions of the city, above ground via galleries and underground earthenware pipes (Çeçen 1996b: 143-145). The *Savaklar maksemi* is a rectangular building measuring 8.25 x 8.25m that underwent many repairs over the centuries. In the interior the incoming water filled several pools and was discharged via noddles (*lüle)* and two outflow galleries.

One of the two branches of the *Savaklar maksemi* transmitted water to the *Tezgâhçılar taksimi* (Altuğ 2022: 148-149). The remains of this distribution chamber are located near the Valens Aqueduct (*Bozdoğan Kemeri*) opposite the *Tezgâhçılar* mosque, in the grounds of a petrol station. There, hidden under a tree, only the top of the distribution chamber's brick dome can be seen, the rest of the building is below the current ground level (**Figure 9**). Whether or not the *Tezgâhçılar* distribution chamber dated from the Roman period and was part of the Hadrianic water way cannot be

Figure 9. Dome of the *Tezgâhçılar taksimi* (Tezgâhçılar distribution chamber), 15th century, near the Valens Aqueduct, situation in 2024 (Photo. Mariëtte Verhoeven).

established. However, it was certainly part of the 15th-century revitalized Hadrianic waterway that became known as the *Kırkçeşme* waterway when it was further expanded in the 16th century by the architect Sinan. The nearby *Kırkçeşme* fountain (see below), from which the waterway got its name, was supplied with water from the *Tezgâhçılar* distribution chamber (Altuğ 2022: 1151-155).

Although not located on the historic peninsula but in the district of Beyoğlu, another distribution chamber worth mentioning is the *Taksim maksemi*.[7] It was built by Sultan Mahmud I (r. 1730-1754) in 1732-1733 together with other water supply facilities belonging to the *Taksim* waterway that had to meet the rising demand of the Galata-Pera region.[8] The *Taksim* distribution chamber, which is located at the *Taksim* square named after it, is an octagonal building with two floors. In

[7] Entry 'maksem' written by K. Çeçen, Türkiye Dinayet Vakfı, İslâm Ansiklopedisi (Religious Foundation of Turkey, Encyclopaedia of Islam), viewed 15 September 2024, <https://islamansiklopedisi.org.tr/maksem>

[8] Ahmet Tabakoğlu 'The history of water in Ottoman Istanbul', Religious Foundation of Turkey, History of Turkey, viewed 15 September 2024, <https://istanbultarihi.ist/558-the-history-of-water-in-ottoman-istanbul?q=water>

Figure 10. Water tower (*su terazi*), 16th century, next to the courtyard wall of the Şehzade mosque complex, situation in 2024 (photo. Mariëtte Verhoeven).

Figure 11. *Ayasofya su terazi* (Hagia Sophia water tower), of unknown date, situation in 2024 (photo. Mariëtte Verhoeven).

recent years the building has been restored by IBB *Miraş*, the heritage department of Istanbul Metropolitan Municipality, and opened in 2024, the year of the 100th anniversary of the Turkish republic, as Republican Museum.

The remains of over thirty Ottoman *su terazi* or water towers to distribute water from waterways and to measure and adjust water pressure still stand in the area of the historic peninsula.[9] As in the case of distribution chambers, since there is no evidence of the presence of water towers in Constantinople before Ottoman times, it is unclear to what extent the Ottoman system of *su terazi* was an imitation or in some cases reuse of Roman-Byzantine precursors. However, the system is certainly similar with lead or ceramic pipes going up and down the water tower with an open tank on top creating a system of inverted syphons (Crow *et al.* 2008: 109; see Kessener 2017: 90-93 for *su terazi*). Two examples of *su terazi* that survived until today, one probably dating from the 16th century (**Figure 10**) and one of 18th-century date are to be found respectively next to and on the courtyard wall of the Şehzade mosque complex, near the Valens Aqueduct. The mosque complex, built between 1543-1549, was commissioned by Sultan Süleyman (r. 1520-1566) to architect Sinan as his first imperial commission. Another *su terazi*, the so-called *Ayasofya su terazi* (Hagia Sophia water tower) (**Figure 11**) stands next to the stone that marks the location of the *milion,* the 4th-century mile marker at the beginning of the former Mese, near Hagia Sophia.

Fountains and Water Kiosks

No fountains have survived in Istanbul from Roman-Byzantine times.[10] The most monumental fountain in the ancient city was the *Nymphaeum*, which was constructed by the city prefect Clearchus under the reign of Emperor Valens in conjunction with de Valens Water line. It was built near the Forum of Theodosius, where now Istanbul University is located.

[9] Kültür Evanteri (Culture Inventory), viewed 15 September 2024, <https://kulturenvanteri.com/tr/arastir/h/?_tur=su-terazisi>

[10] A possible exception are the remains of a cistern in Unkapanı (located between the Medipol University building and Fil Yokusu near Atatürk Boulevard) with a brick façade with niches recently identified with some caution by Kerim Altuğ as a fountain dating from the Middle Byzantine period. Altuğ 2022: 150-151.

Figure 12. So-called Serpent Column, 5th century BCE, on the former Hippodrome, situation on 2015 (photo. Mariëtte Verhoeven).

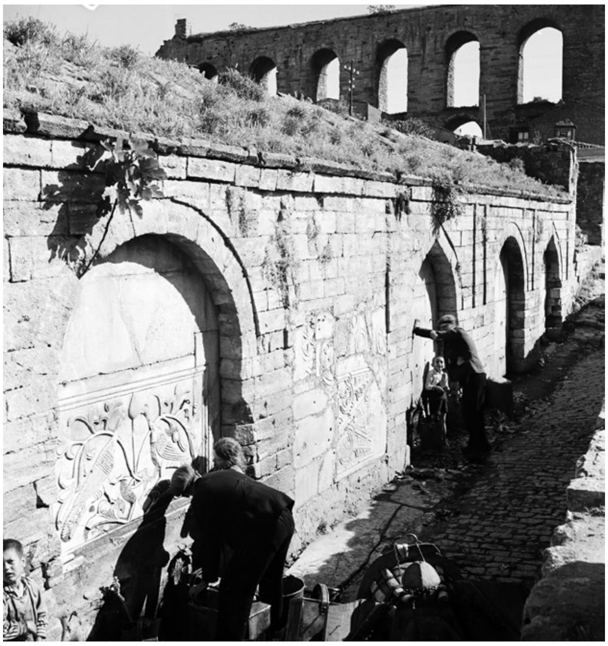

Figure 13. *Kırkçeşme* (Forty Fountains) Fountain, *c.* 1453, with a Byzantine relief (7th century CE) depicting peacocks, now in the collection of the Istanbul Archaeological Museums. Photo of situation in 1935. Nicholas V. Artamonoff Collection (© Dumbarton Oaks Research Library and Collection. Trustees Harvard University, Washington, DC).

There is a preserved ancient monument, however, which can be considered a fountain although of an exceptional form. In 1856, during excavations in the former Hippodrome of Constantinople underneath the so-called Serpent Column (**Figure 12**), a stamped fistula was found (Stephenson 2016: 22-25). More than 150 *fistulae*, lead pipes, many of them stamped, survive from ancient Rome (Kleijn 2001). In contrast, the stamped fistula found in the Hippodrome is the only one that has been archaeologically attested for Constantinople. The bronze Serpent Column originally stood in Delphi as part of a monument commemorating the Greek victory over the Persians at the battle of Plataea in 479 BCE and was presumably brought to Constantinople by Emperor Constantine after 330 CE. The fistula found underneath it indicates that the column was probably transformed into a fountain shortly after the construction of the Valens line in 373, with water flowing from the three snake heads depicted, among others, in the later 16th-century illustrated manuscript Hünernâme (Book of Talents).

From the Ottoman era, more than a thousand fountains (*çeşmes*) and almost 70 water kiosks (*sebils*) have been preserved in Istanbul.[11] The difference between the two is that people could drink or take water from a public fountain whereas at a *sebil* (meaning 'road') cold drinking water was provided free of charge to the people. Both fountains and *sebils* were *waqf* facilities. Commissioning and endowing fountains and *sebils* were regarded as charitable work. Almost all fountains and *sebils* are adorned with an inscription featuring lines from poems. These inscriptions give details about the good deed of sharing water as well the name of the commissioner and the date of foundation. Many of the fountains and especially *sebils* belonged to mosque complexes but every neighbourhood also featured fountains in public squares and streets. Fountains of different shapes, sizes and styles have been preserved ranging from modest wall fountains to monumental freestanding fountains. *Sebils* were designed in the form of freestanding or semi-freestanding buildings with a dome or integrated into a building with a single window from which the water was distributed. Many of the surviving *sebils* are still in use as kiosks for selling drinks and snacks. Only a few notable examples of fountains and *sebils* are presented here.

The *Kırkçeşme* (Forty Fountains) Fountain was actually a series of public wall fountains near the Aqueduct of Valens commissioned by Sultan Mehmed II after the conquest of Constantinople in 1453. It got its water from the *Tezgâhçılar* distribution chamber (see above) and gave its name to the *Kırkçeşme* waterway, the expansion of the 15th-century waterway by the architect Sinan of a century later. The fountain was demolished when Atatürk Boulevard was built in the 1940s. One of the fountains was decorated with a Byzantine relief depicting peacocks (**Figure 13**), which is now in the collection of the Istanbul Archaeological Museums.

[11] The section on Ottoman fountains and *sebils* is mainly based on Nur Urfalioğlu, 'Fountains and Sebils of Istanbul', Religious Foundation of Turkey, History of Turkey, viewed 15 September 2024, <https://istanbultarihi.ist/712-fountains-and-sebils-of-istanbul>, unless otherwise mentioned. Ablution fountains at mosques are not considered here.

Figure 14. *Ayşe Sultan* Fountain, 1603-1604, next to the courtyard gate of the *Şehzade* Mosque complex, situation in 2024 (photo. Fokke Gerritsen).

Figure 15. Fountain and *Sebil* of *Ahmed III*, 1728-1729, in front of *Bab-ı Hümayun* Gate, the entrance of *Topkapı* Palace, situation in 2019 (photo. Mariëtte Verhoeven).

The *Ayşe Sultan* Fountain (**Figure 14**) is an example of a foundation by a woman. The fountain was a commission of Ayşe Sultan (*c.*1565-1605), daughter of Sultan Murad III (r. 1574-1595), who dedicated it to her husband Ibrahim Pasha, after his death in 1601. He is commemorated in the two inscriptions decorating the fountain. The fountain has a beautiful carved oyster shell decoration at the top of the niche. The fountain was built in 1603-1604 and is located next to the courtyard gate of the *Şehzade* Mosque complex, where Ibrahim Pasha is buried. Like the mosque complex, the fountain was recently restored including the installation of a tap with running water.

The Fountain and *Sebil* of *Ahmed III* (**Figure 15**) was built on the site of a Byzantine fountain called Perayton, now in front of *Bab-ı Hümayun* Gate, the entrance of *Topkapı* Palace.[12] The fountain is one of the most beautiful examples of architecture from the so-called Tulip Era, which roughly coincides with the first quarter of the eighteenth century. In architecture of this period traditional Ottoman elements were blended with the Baroque and Rococo style from the West. The Fountain and *Sebil* of *Ahmed III* is the most monumental fountain in the area of the historic peninsula. The rectangular building has fountains on all four sides and *sebils* at every corner. On the overhanging lead-coated roof are five domes. The inscription on the building indicates that it was built between 1728 and 1729 by order of Sultan Ahmed III on the recommendation of Grand Vizier Nevşehirli Damad İbrâhim Pasha. A long eulogy by the poet Seyyid Vehbi, consisting of 28 couplets, is engraved on the four sides of the building.

Figure 16. *Seyyid Hasan Paşa Sebil* and Fountain, 1745, situation in 2024 (photo. Mariëtte Verhoeven).

Another example of a combination of a fountain and *sebil* but of much more modest size is the Baroque-style *Seyyid Hasan Paşa sebil* and fountain, again named after its commissioner who had it built in 1745 (**Figure 16**).[13] The *sebil* and fountain are part of a building that also housed a primary school and shops and is located behind the *Bayezid II* hammam. In this case the *sebil,* which is located to the left of the door that gives entrance to the building is much larger and more refined than the modest fountain with a pointed arch niche to its right. The *sebil* and fountain, together with the protruding

[12] Koç Üniversitesi Digital Collections, viewed 22 February 2025, <https://librarydigitalcollections.ku.edu.tr/en/digital-exhibitions/fountain-of-ahmed-3/> Other information was taken from Türkiye Dinayet Vakfı, İslâm Ansiklopedisi (Religious Foundation of Turkey, Encyclopaedia of Islam), viewed 15 September 2024, <https://islamansiklopedisi.org.tr/ahmed-iii-cesmesi–topkapi-sarayi>

[13] Türkiye Dinayet Vakfı, İslâm Ansiklopedisi (Religious Foundation of Turkey, Encyclopaedia of Islam), viewed 15 September 2024, <https://islamansiklopedisi.org.tr/seyyid-hasan-pasa-kulliyesi>

roof, form the opulent façade of the simple stone building behind it that housed the primary school.

Water Heritage for the Future

In the edited volume *Adaptive Strategies for Water Heritage. Past, Present and Future* (2020) Carola Hein acknowledged water heritage as a crucial source of information both for the functioning of water systems in the past and discerning its impact on the present (Hein 2020: 2). She also noted that 'Overall, water's potential to connect sites of living heritage with each other; water related heritage's capacity to connect past, present, and future; and water's role as heritage in spatial developments, landscape design, and urban planning remain underestimated and underexplored'(Hein 2020: 3). An important initiative of Hein and others to fill this gap is the biannual open access journal *Blue Papers* which highlights the critical role of water and heritage in sustainable development.[14] In volume 2, no. 1, published on the occasion of the UN Water Conference 2023 in New York, we had the opportunity to present the case study of the Valens Aqueduct in Istanbul both in the journal as well as at the official side event of the UN Water Conference '*Water and Heritage: Connecting Past, Present and Future*' at the Harlem Stage in New York.[15]

Another initiative that must be mentioned here is the *Water in Istanbul: Rising to the Challenge?* project (2021-2023) in which archaeologists, engineers, social scientists and historians from the University of Edinburgh, Northumbria University, Istanbul Technical University (ITU) and the British Institute at Ankara (BIAA) investigated the water management infrastructure of Istanbul and explored how past practices can inform solutions to contemporary water-related challenges.[16] One of the achievements of this project is the creation of a GIS model of the complex systems that supplied water to Istanbul's first hill, an area of 70ha, including Hagia Sophia and the *Topkapı* Palace.

Whereas the aforementioned project mainly focuses on the technological and functional aspects of water management infrastructure of Istanbul, under the umbrella of the *Urban Heritage Lab* of the Netherlands Institute in Turkey (NIT), where we collaborate with academic, public and private partners from Türkiye and the Netherlands, we developed several initiatives concentrating on Istanbul's multi-layered water heritage and the role it can play for current and future water-related challenges. Today, water flows from the tap at home or can be bought in bottles but the journey the water makes and the efforts that must be made to provide freshwater to sixteen million Istanbul residents daily are not visible. Water heritage on the other hand is visible everywhere in the historic heart of Istanbul. However, most of these physical remains have lost their function. Water is no longer supplied over the historic aqueducts; the cisterns no longer serve for water storage and water no longer comes out of the taps of most fountains. Thus, water and heritage are disconnected. We take as a premise that by restoring the relationship between water and heritage it can play a role in creating awareness for current and future challenges related to water supply and use.

Figure 17. Valens Aqueduct (*Bozdoğan Kemeri*), founded in 373 CE, situation in 2024 (photo. Mariëtte Verhoeven).

We see the aforementioned Valens Aqueduct (**Figure 17**), an imposing structure in the heart of Istanbul representing centuries of multi-layered history of urban water supply, as an ideal showcase to tackle the challenges of developing a greater awareness of the precious value of water, and to restore the relationship

[14] Blue Papers: Highlighting the Critical Role of Water and Heritage in Sustainable Development, <https://bluepapers.nl/index.php/bp>
[15] The event was organized by ICOMOS (ISC Water and Heritage, NL and US), the UNESCO Chair on Water, Ports and Historic Cities, the engineering firm Witteveen+Bos and the Water Authority Amstel, Gooi en Vecht (AGV), and supported by the Union of Water Boards, The Netherlands, the ICOMOS International Scientific Committee on Underwater Cultural Heritage (ICUCH), and the ICOMOS Sustainable Development Goals Working Group (SDGWG).
[16] British Institute at Ankara, viewed 15 September 2024, https://biaa.ac.uk/wp-content/uploads/2022/01/HT11_08_Water_in_Istanbul.pdf>

between water and heritage. The aqueduct is a national monument located within the boundaries of the 'Historic Areas of Istanbul' UNESCO World Heritage Site.[17] The aqueduct was restored between 2018-2024 on behalf of the Istanbul Water and Sewerage Administration (ISKI), the legal owner of Istanbul's historic water structures. The restoration focused primarily on strengthening and cleaning the structure (**Figure 18**). However, the monument still faces several threats, including air pollution, ongoing urbanization and uncontrolled use of the aqueduct by citizens (**Figures 19 and 20**), putting the integrity of the monument at risk.

The Valens Aqueduct was the case study of a brainstorm session exploring sustainable solutions for increasing knowledge and public engagement at a workshop with representatives of Dutch and Turkish heritage organizations, NGOs and the creative industry organized in September 2022 in Istanbul.[18] Two approaches emerged from the brainstorm session: the use of digital technologies, such as projections and apps, to disclose the multi-layered history of the monument without physical interventions, and the use of the aqueduct as a stage and backdrop for cultural activities such as a Water Festival on World Water Day, with activities around the theme of water in past, present and future.

To educate (future) heritage experts, planners and designers we developed an interdisciplinary academic course *Water Heritage for Sustainable Cities* (September-December 2022) for graduate students and junior professionals from the Netherlands and Turkey.[19] The course familiarized participants from a range of disciplinary backgrounds – architecture, urban planning, heritage studies, history, arts – with perspectives on water and heritage, especially those related to contemporary water challenges in a context of climate change and urban development. In a research-by-design exercise, participants learned to work in an interdisciplinary team to design proposals for the revalorization of the Valens Aqueduct and the surrounding area. This resulted in proposals from four teams (Verhoeven *et al.* (eds) 2023b). The first proposal, *Reconceiving the Source of Life of the City Through Intervention – Intersection – Interaction -Integration*, attempts to restore the link between the aqueduct and

Figure 18. Restoration of the Valens Aqueduct (*Bozdoğan Kemeri*), founded in 373 CE, situation in 2022 (photo. Mariëtte Verhoeven).

Figure 19. Valens Aqueduct (*Bozdoğan Kemeri*), founded in 373 CE, situation in 2022 (photo. Mariëtte Verhoeven).

Figure 20. Interior of the Valens café, situation in 2022 (photo. Mariëtte Verhoeven).

[17] UNESCO World Heritage Convention, viewed 15 September 2024, <https://whc.unesco.org/en/list/356/>

[18] The workshop was organised as part of a fellowship for which I was awarded a grant from the Science Diplomacy Fund of the Dutch research Council (NWO) and the Ministry of Foreign Affairs of the Netherlands to spend three months in Istanbul in 2022 to conduct research on Istanbul's water heritage. For a video impression of the workshop see: <https://www.youtube.com/watch?v=9L3CB8yYJ1k>

[19] Water Heritage for Sustainable Cities, Netherlands Institute in Turkey, viewed 15 September 2024, <https://www.nit-istanbul.org/education/nit-urban-heritage-lab-water-heritage-for-sustainable-cities-course>

the surrounding neighbourhoods.[20] To create a better connection between the neighbourhoods on the west and east sides of the busy thoroughfare under the Valens Aqueduct, the group proposes constructing a raised walkway for pedestrians. This brings people in direct contact with the structure and provides an opportunity to use the space between the arches for temporary exhibitions on art, but also on sustainability or heritage, for example. Second, the team proposes to use the former watercourse on top of the aqueduct to collect rainwater and use it at walking level for the park on either side of the road.

Making the space around the aqueduct greener is an important goal of the second proposal, *Pursuing Water through a Historical and Permeable Ecological Corridor. An Open-Air Museum Concept*, which combines the creation of a pedestrian area and an ecological corridor.[21] By organizing social activities, workshops and markets, the area becomes a meeting point for residents in the area. Part of the aqueduct, where the Kalenderhane mosque is located, as well as a fountain and a cistern, will be set up as an open-air museum where people can learn about the functioning of the historic water system.

The third proposal, *Field of Flowing Memory: Bringing Water Back to the City*, takes a more rigorous approach in terms of redesigning the area, proposing that the thoroughfare that now wriggles between the arches of the aqueduct be routed through a tunnel.[22] This will provide a large free space. Part of it will be used to collect, sanitize and reuse rainwater and wastewater for a wetland site to be constructed. An 'amphitheatre' sunken into the ground provides space for cultural activities with the aqueduct as a backdrop in the summer, while in the winter it can serve as an additional water collection location during times of prolonged rainfall.

The fourth proposal, *The Valens Aqueduct as an Urban Living Lab: Integrating Networks, Enhancing Interfaces, and Revealing the Identity*, wants to restore the broken connection between the aqueduct and the city's residents primarily by using the aqueduct and its immediate surroundings as a space where all kinds of stakeholders, from local governments to resident groups, from students from the neighbouring university to entrepreneurs and cultural organizations in the area, can collaborate on heritage and water.[23] An 'urban living lab', as the group calls it, where decisions about possible interventions in the area are taken together. An accompanying walking app allows residents and tourists to find out more about the area's water heritage.

Thanks to the granting of a Connected World Social Impact Award by the Vrije Universiteit Amsterdam in 2024, we partnered with the Hrant Dink Foundation, a Turkish NGO, to develop a self-guided walking tour dedicated to Istanbul's water heritage. The tour has been available as a thematic tour in the mobile application KarDes since February 2025.[24] KarDes is a mobile application in English and Turkish that already has a significant impact through its memory tours focusing on the heritage of religious and ethnic minorities in major Turkish cities such as Istanbul, Ankara and Izmir. The 'Istanbul's Water Heritage' tour offers narratives and images regarding the tangible and intangible water heritage in Istanbul through the ages. It does not just emphasize the continuities and breaks in water supply and usage over more than 1600 years, but also highlights the shared importance of water and water-related culture across ethnic and religious divides. The walking route runs from north to south across the historic peninsula, from the the Valens Aqueduct and its surroundings to the shore of the Sea of Marmara. Stops include the so-called Armenian Fishermen church (*Surp Harutyun Kilesi*), the *ayazma* (spring) of a Greek church, the remains of the Roman bath next to the Kalenderhane mosque, Byzantine cisterns, and Ottoman water towers, fountains and hammams. The tour focuses not only on the material remains but also on the stories and legends pertaining to water culture such as those about the *sakas* (water carriers and the healing power of holy springs.

Scholarly research underpins our outreach activities and plans. Research data, including source texts and images, on water heritage systems and installations in Istanbul over the centuries are stored in a database called Istanbul-Su, which is accessible to a wider audience via a web application.[25]

Conclusion

A large number of physical artefacts attest to Istanbul's rich history of water supply, management, and use over the centuries. This water heritage can potentially play a role in dealing with and in creating awareness about current and future water-related challenges. However, most objects lack the element that was the reason for their existence, and that is water. To make this heritage

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[23] Team members: Cem Almurat, Gökhan Okumuş, Itminan Tasneea, Özge Özeke Eski, Sıla Akman Aşık.
[24] Kardes Mobile Application, Hrant Dink Foundation, viewed 22 February 2025, <https://hrantdink.org/en/activities/projects/cultural-heritage/2177-discover-istanbul-with-kardes-mobile-application>
[25] The database and web application were developed by Radboud University's Humanities Lab.

relevant, it is necessary to restore the relationship between heritage and water.

The first condition for restoring the connection between heritage and water is to acknowledge the importance and potential of water heritage.[26] This manifests itself firstly in the preservation and restoration of objects for the future. Only some of the water heritage is well-preserved and restored, including historic aqueducts and cisterns. Many fountains have also been restored in recent years as part of the restoration of Ottoman mosque complexes under the authority of the General Directorate of Pious Foundations (*Vakıflar Genel Müdürluğü*) of Istanbul. In 2020, Istanbul Mayor Ekrem İmamoğlu announced a plan to restore the city's public fountains, including restoring the water supply through the taps. Forty fountains, including the monumental fountain and *sebil* of Ahmed III, were restored by IBB Miraş, the heritage department of Istanbul Metropolitan Municipality, the same year and the goal is to reach this number every year.[27]

However, to fully exploit the potential of Istanbul's rich water heritage, preservation and restoration of stand-alone monuments and artifacts is not enough. They now stand as silent witnesses to a rich past that do not reveal the story of their history and function as installations that were part of ingenious water systems that supplied the thirsty city with water. Through the initiatives and plans presented in this chapter, we aim to restore the connection between heritage and water in various ways to not only increase knowledge about the past but also to create awareness of current and future water-related challenges. We see a big role here for ISKI, Istanbul Water and Sewerage Administration, the organisation that has to supply an estimated 16 million people every day with freshwater, 50 per cent of which comes from other provinces because Istanbul's own reservoirs are drying up (İlhan 2021). ISKI is also the legal owner of Istanbul's historical water heritage, including the recently restored Valens Aqueduct which we consider an ideal showcase to tackle the challenges of developing a greater awareness of the precious value of water, and to restore the relationship between water and heritage.

On 6 June 2024 the 'Water Heritage Istanbul' symposium in Istanbul was organised by the Dutch Consulate-General, the Netherlands Institute in Turkey (NIT) and ISKI.[28] ISKI presented there completed, ongoing and planned restoration projects of historic water structures as well as the public events they organize around it such as tours along these structures and activities for different groups among which are school classes at the recently opened Terkos Water Civilisations Museum located in the former Terkos pumping station. Representatives of ISKI's counterpart in Amsterdam, Waternet, focused on the role of water heritage for future challenges and inclusive decision making in water management. As a representative of NIT's *Urban Heritage Lab*, I had the opportunity to present our ideas and proposals for the Valens Aqueduct. We see this as an important first step towards the involvement of ISKI in the implementation of one or more ideas to result in the revalorisation of the Valens Aqueduct. This would allow ISKI, through storytelling, installations, festivals and a possible redevelopment of the area, to link the past to the present by making visible the efforts that need to be made in the present to provide water to the still thirsty city.

[26] The monuments located on Istanbul's historic peninsula were included in the UNESCO World Heritage List in 1985. The Valens Aqueduct, however, is the only water-related monument specifically mentioned, besides cisterns and fountains in general. UNESCO World Heritage Convention, viewed 15 September 2024, <https://whc.unesco.org/en/list/356/>

[27] Bloomberg, 21 September 2021, viewed 15 September 2024, <https://www.bloomberg.com/news/features/2021-09-21/free-public-drinking-water-from-old-istanbul-fountains>

[28] The symposium was organised in the framework of the 2024 celebrations of the 100th year of the Friendship Treaty between The Netherlands and Türkiye.

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The archaeology of irrigation technology and water management encompasses a wide range of structures – subterranean tunnels (*qanāts*, *falaj*, *foggara*, *ghayl* etc.), reservoirs, cisterns, canals, aqueducts, tanks, fountains, water mills, wells, dams, barrages - in a variety of contexts - mountains, deserts, forests, agricultural, horticultural, urban, village, military, riverine, estuarine, coastal, lacustrine – and over a long time period from the seventh through to nineteenth centuries. However, in many areas the archaeology of these facilities remains little explored. This volume begins to rectify this through a variety of case studies examining the diverse ways that past populations have developed hydraulic infrastructure for moving and managing water across the Islamic World. It also considers how past human ingenuity in developing hydraulic infrastructure, now often fallen into disrepair and dis-use, could hold lessons for the present and offer solutions for the future as humanity faces the challenges of environmental and climate change.

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