JOINT PROJECT

Rehabilitating Water Distribution Systems as an Adaptation to Climate Change

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I. INTRODUCTION

Water management systems across the MENA countries employ a variety of techniques, according to physical situations, climates, existing materials, and people's needs. Water infrastructure is typically controlled and operated at the local level. In both rural and urban communities, people are both the initiators and managers, but also the warrantors, of these systems.

Due to bad management and the subsequent introduction of new technologies, most of these traditional systems have broken down during the last century. Additionally, much of the knowledge of water-management techniques and operations has disappeared: both use of the systems has declined as well as the confidence of the people in those systems. Today, deficient water management by public authorities combined with the economic, social, and environmental costs of large infrastructure projects, have pushed civil society groups in many Arab countries to re-examine traditional techniques and support their re-appropriation. Moreover, successive droughts in arid and semi-arid areas have led a growing number of communities, particularly rural ones, to opt for alternative solutions such as rainwater harvesting in underground cisterns or artificial ponds.

The objective of this research is to evaluate the extent to which traditional water systems may reduce the pressure on water demand in three case study areas in Yemen, Jordan, and Morocco. The study will address the following questions:

- What are the main traditional water storage, collection and distribution systems in the case study areas?
- What is their size, water capacity and quality?
- Can and should these structures be rehabilitated?

II. METHODOLOGY

Three countries were investigated for this study. There is extensive accumulated local knowledge in water management and systems rehabilitation; this local knowledge can be seen as having a common methodology with modern scientific approaches. In each case study area the following was collected:

- Information on the existing local water distribution systems including the size/dimensions of each system, the amount of water produced and the quality of water produced. This information was gathered by on-site measurements and testing of acidity/pH, environmental conditions, and biological parameters. Knowing the size of each system and the number of users helps determine the capacity of the system.

- Information about water management and local systems operation and maintenance. This was collected from the local authorities.

- Opinions and behaviors of the users of both public and traditional systems. This will be based on a small survey of local farmers conducted by a questionnaire. The estimated number of farmers to complete the questionnaires ranged between 20 and 30 in each case study area. The questionnaires provide useful information about indigenous knowledge of the traditional water management systems and behavior regarding water use from public networks. This information helps inform the analysis regarding future water management needs and indicates the perceived efficiency of water use in different systems.

III. LITERATURE REVIEW

There is a body of scholarship focused on the issue of alternative systems of water supply. The literature highlights two main phenomena: the growing dissatisfaction of civil society with current water-management systems and a movement toward the rehabilitation of alternative management systems. The development and decline of traditional water management systems in the MENA region has been explored mostly by historians, and the available research is scarce. A few hallmarks of these systems, as described in the literature, are summarized below.

Role of non-state actors in the development of traditional systems
The major role played by philanthropists and local communities in the construction and maintenance of traditional water management systems is a permanent feature across the region (Zaki, M. O, 2001).

Circulation of know-how
In water management, the technology transfers from the Middle East and Persia (in particular) to South Asia are historically acknowledged: "The technology of *qanat* was adopted by the people of MENA to build *swaqi/cisterns* to meet their drinking water needs" (Agarwal and Narain, 1997, p.29).. The *qanat*-based water supply system in the town of Burhanpur in Madhya Pradesh, India is an example of this transfer of knowledge (Agarwal and Narain, 1997, p.29).

Local needs, sustainability and the decline of traditional water management systems
Leyes Ferrouki (1997) underscores that:

> …Even though these traditional rainwater harvesting systems can look precarious and casual in the eyes of modern technologists, they have been perfectly suitable for centuries. The reason for this is that they are compatible with local lifestyles, institutional patterns and social systems. They represent a fund of solid experience gained through generations of observations, trials and errors.

The know-how associated with such techniques is a major source of cultural and scientific heritage. Ferrouki notes that "…many of these techniques have disappeared or are disappearing along with their innovators, since the modern civilization is forcing them to abandon their land and ways of living." It is increasingly important to identify the historical factors that have generated and accelerated the disinterest of communities in the MENA region in their own water-management systems, and the willingness to replace them with high-cost and often low-efficiency technologies in a context of ever growing water scarcity.

1. Jordan: Overview of the Yarmouk-Decapolis Tunnel

The north of Jordan is the site of a hidden underground marvel: the world's longest antique aqueduct system, known as the Yarmouk-Decapolis Tunnel (Fig 1). Research suggest that it was built in Roman times, much of it probably after 130 AD (Döhring, 2008). Not documented by classical authors, it also escaped modern attention for a long time. Local inhabitants, however, know about its entrances and are familiar with the different segments of the tunnel.

A few Jordanian researchers have studied aspects of the tunnel (Al-Madi and Al-Musa, 1959; Sreheen, 1985; Al-Malabeh, 2005, 2007; Al-Malabeh et al., 2008) and archaeological studies have examined the terminal sections at Umm Quais/Gedara (Kerner, 2004) and the sections at Wadi Shelalah (Rababeh, 1995; Bienert, 2004). It was only recently suggested the tunnel was one large, continuous structure (approximately 100 km long) that delivered water from Syria, across the Al-Shalallah valley and then on to Abila and Gedara (Döhring, 2004, 2008).This theory, however, still awaits verification. It is notable that so far only a few tunnel segments have been explored scientifically, surveyed in detail, and published (Rababeh, 1995; Bienert, 2004; Döhring, 2008, Al-Malabeh and Kempe, 2013).

Many portions of the tunnel still exist in an excellent to very good condition, with little damage. These segments, which extend from one to 10 km, are used for irrigation by the local farmers.

The water inside the tunnel ranges from a level of 40 cm up to one meter and is of good quality for agricultural use. The Yarmouk-Decapolis Tunnel is an important method for water harvesting and can help address water shortages in the area and increase resilience to climate change.

Figure 1: Field Photograph inside the Yarmouk- Decapolis Water Tunnel System, Jordan.

2. Yemen: Overview of the Tawilah Cisterns Complex

The Tawilah Cisterns storm water drainage and harvesting system has developed over a long period of time. The old system of the historical city is widely believed to have been constructed by the Himyarites, who developed a great civilization in south Arabia between 115 BC and 500 AD. It was an intricate water system comprising a series of cascading cisterns of varying shape and capacity, and waterways carved out of solid volcanic rock and lined with a thick coat of fine stucco, resembling marble. At some unknown point of time, the system was completely buried, filled with stones and covered by soil that washed down from nearby mountain slopes.

The system was rediscovered by the British who occupied Aden in 1839. The British, in their attempt to restore the old system, changed it significantly. Originally there were about 53 collection tanks (Norris & Penhey, 1953) but only 13 remain following a succession of renovations, including those done by the British in the 19th century. The existing tanks have a combined capacity of about nineteen million gallons (Fig. 2).

The original system of tanks had the double-purpose of collecting and distributing rain water and protecting the city from the ravages of floods by ensuring the safe drainage of storm water generated from the large barren rock catchment of the Aden Plateau.

The present status of the historic storm water drainage system is very poor due to its age, the limited amount of repair and maintenance work, and bad management. The existing flood control structures in the catchment were not effective and the capacity of the old storm water drains was not enough to discharge the floodwater of the 1993 storm. However, with the removal of sedimentation and some basic renovation the system capacity can be restored to once again provide effective flood control.

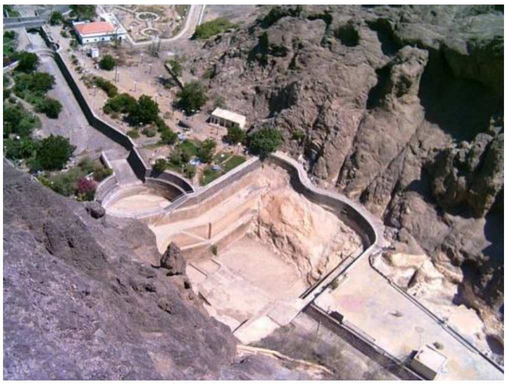

Figure 2: Tawilah Cisterns Complex, Yemen

3. Morocco: Overview of the Khettara network in Tafilalet

The Tafilalet plain, located in southeast Morocco in a pre-Saharan area, is characterized by an arid climate and a large deficit in the water budget due to low quantities of rainfall. It receives on average less than 200 mm of rainfall/year, and often less than 100 mm. However, agriculture is the most important activity in the region and represents the primary source of income. Agricultural land and date palms (in oases covering the center of the plain and forming the largest palm grove in the Maghreb (700 km^2)), are irrigated primarily by groundwater. The plain is crossed by the Ziz and Rheris rivers, flowing from the mountains of the High Atlas.

A 300 km network of khettara or subsurface irrigation channels (or *qanat*) was built in the Tafilalet basin beginning in the late 14th century. More than 75 of these channels provided perennial water following the breakup of the ancient city of Sijilmassa. Khettaras continued to function for much of the northern oasis until the early 1970s.

Insufficient water resources and unsustainable practices have dramatically lowered the water table, drying up the khettaras. This has resulted in a loss of local control over water resources, abandonment of a sustainable irrigation system, and progressive desiccation. In 1967 there were more than 800 channels of which 570 were operational in the area of Tafilalet; in 2005 only 410 channels remained, 191 of which were operational.

Local inhabitants give three essential reasons for the degradation of khettaras and the decrease in their number. The first reason is related to the dramatic decrease in quantities of rain—the lowest recorded in 25 to 30 years. This has reduced the quantities of water available in the basement. The second reason is an increase in the quantities of water extracted from the water-table and used by recently-established big farms in the area. The third reason is the lack of qualified human resources to restore and manage the system, due largely to migration.

IV. CASE STUDIES

1. Jordan

Survey Results

A majority of the interviewees were landowners and farmers (mostly male) in the Irbid governorate located in the far north-west of Jordan. Water there is used for households as well as commercial irrigation, predominantly of figs, almonds, olives, pomegranates, and grapes. Most of the farms are less than 25 *donums,* i.e. small-medium size farms. As a number of interviewees use the tunnels for irrigation, they see great value in their rehabilitation and upgrading.

Two major causes for the tunnel’s deterioration over the last few years are lack of government maintenance and destructive human practices. Because the tunnel is public property, the government or local authorities are seen as the main entities responsible for its general maintenance, restoration, and management. But support and input from the local community, particularly the farmers, is encouraged. Respondents feel that the needed labor for system operation and maintenance is available; however, many believe that this labor force needs better training and pay, as the workers come from underprivileged groups in nearby villages.

Most respondents admitted to using supplementary water sources such as wells and rainwater harvesting. Although the water quantity in the tunnel is considered sufficient, it is often of poor quality for household use and can be difficult to access.

Not all users of the Yarmouk-Decapolis Water Tunnel System actually pay for the water they use. About 43% of respondents said they did not pay for water from the tunnel. In sum, More than half of respondents wanted to rehabilitate the system because they believe it could be a good source of water.

<u>Technical Parameters</u>

Ten water samples along the Decapolis Tunnel were collected and the following parameters examined:

- pH
- EC
- TDS
- Temperature
- Nitrate
- Sulfate
- Cations
- Bicarbonate
- E. coli (bacteria)

Concentrations of Na+ and K^{+} were determined by using fame photometer. As for Ca^{+2}, Mg^{+2}, $HCO3^{-}$ and Cl^{-} concentrations, these were determined by a volumetric titration method, and $SO4^{-2}$ and $NO3^{-}$ spectro-photometrically. The total dissolved solids (TDS) content was calculated using the following equation (TDS (mg/L) = EC*0.64).

Selected water springs were chosen along the tunnel to test the quality of water that recharge the tunnel. The chemical analyses were carried out for two main springs in the area, Hobras and Abila (Qwillebeh).

The studied samples show pH-values range between 7.31–7.96, for Abila, and 7.21–8.84 for Hobras. EC (µs/cm) was 704–641 for Abila and 465–601 for Hobras. The temperature was 21–24^{o}C for Abila and 20–26^{o}C for Hobras.

The cationic concentrations in (meg/l) are as follows:

- Ca^{+2}: 1.81–2.22 for Abila, 0.85–1.63 for Hobras
- Mg^{+2}: 0.71–1.68 for Abila, 0.45–2.14 for Hobras
- K^{+}: 0.08–1.24 for Abila, 0.62–2.45 for Hobras
- Fe^{+2}: 0.03–.08 for Abila, 0.01–0.07 for Hobras
- $SO4^{-2}$: 0.18–0.47 for Abila, 0.12–0.54 for Hobras
- $NO3^{-}$: 0.18–0.47 for Abila, 0.12–0.54 for Hobras
- $HCO3^{-}$: 0.54–1.44 for Abila, 0.85–1.63 for Hobras
- Cl^{--}: 0.31–1.55 for Abila, 0.44–2.81 for Hobras

Parameter	Abila	Hobras
Ca+2	1.81–2.22	0.85–1.63
Mg+2	0.71–1.68	0.45–2.14
K+	0.08–1.24	0.62–2.45
Fe+2	0.03–.08	0.01–0.07
SO4-2	0.18–0.47	0.12–0.54
NO3-	0.18–0.47	0.12–0.54
HCO3-	0.54–1.44	0.85–1.63
Cl--	0.31–1.55	0.44–2.81

Finally, the E. coli results indicate that all of the investigated samples suffer from slight biological pollution.

The main conclusion from that the water analyses of the springs is that they are suitable for irrigation and planting purposes.

2. Yemen

Survey Results

Questionnaires were collected from 70 adults. When asked about general water use, two percent of interviewees answered that they use the water to irrigate gardens surrounding the cisterns; others respondents stated that they do not use water directly from the cisterns because of sedimentation and algae. Most respondents said that they get water from government pipelines, because the cistern is located in an urban area and 100% of the city is covered by public networks and sufficient for all users with good quality.
Most of interviewees were not aware of the cisterns, because they said these were the responsibility of the local authority. Most of those who were aware believed the main function of them to be flood protection. The rest believed them to be for rainwater storage and for emergency uses. Most respondents blamed the government and lack of maintenance for the deterioration of the system, and think it should be rehabilitated.

Interviews of government officials led to different findings. One hundred percent of the respondents said all of Aden's residents benefit from the Tawilah complex, as it protects the city from floods. Most of them believed water from the cisterns is not safe for direct drinking due to algae and sediment, but that it could be after a simple treatment. They felt the water was suitable for agricultural purposes.

Most respondents agreed that management of the complex is the responsibility of local authorities, that that labor is available for systems operation and maintenance. However, many feel that this labor force needs better training and pay, as the workers come from underprivileged groups in nearby governorates. Overall, the system needs to be rehabilitated and maintained by those with traditional knowledge of local building materials and conditions.

Technical Parameters

Five samples water Quality of Aden Crater wells (Mosques wells) were collected from different points and the following parameters examined:

- Sodium, potassium, calcium carbonate, magnesium
- Total alkalinity
- Sulphates
- Chlorides
- Bicarbonates
- Nitrates
- Total dissolved solid
- pH
- Conductance (µ S/cm)
- E. coli – FC bacteria.

During the field work, the cisterns were empty. Therefore samples were taken from wells located inside the mosques below of the cisterns complex. The reason of that, the seasonal rains which gather on the Crater plateau and are stored in the cisterns and are located inside the mosques and are the main source of water for Crater wells.

The chemical analysis of the studied samples show the following concentrations (ppm):

- Sodium, 283–563
- Potassium, 4.3–17.2
- Calcium hardness expressed as calcium carbonate, 10–440
- Magnesium hardness expressed as calcium carbonate,126–617.2
- Total hardness expressed as calcium carbonate, 260–566
- Total alkalinity, 234–310

- Sulphates, 276–844
- Chlorides, 300–412
- Bicarbonates, 285.4–378.2
- Nitrates, 90–180
- Total dissolved solid, 13,376–2,073
- pH, 7.5–8.5
- Conductance (µ S/cm), 2,150–3,240.

The bacteriological results show that all of the samples were polluted with E. coli FC bacteria.

These chemical and bacteriological analyses demonstrate that the water is not suitable for drinking.

The catchment area of the Tawilah Cisterns is 3.5 km^2. The length of the conducting channel to the sea is 1.95 km. The total capacity of the main Tawila tanks is 39,700 m^3. The table below shows capacities of individual tanks.

Table (1) Main Tawilah Tanks and their Capacities

Tank	(Capacity m^3)
Tank 1	3,700
Tank 2	1,000
Tank 3	18,000
Tank 4	800
Tank 5	500
Tank 6	800
Tank 7	400
Tank 8	14,500
Total	39,700

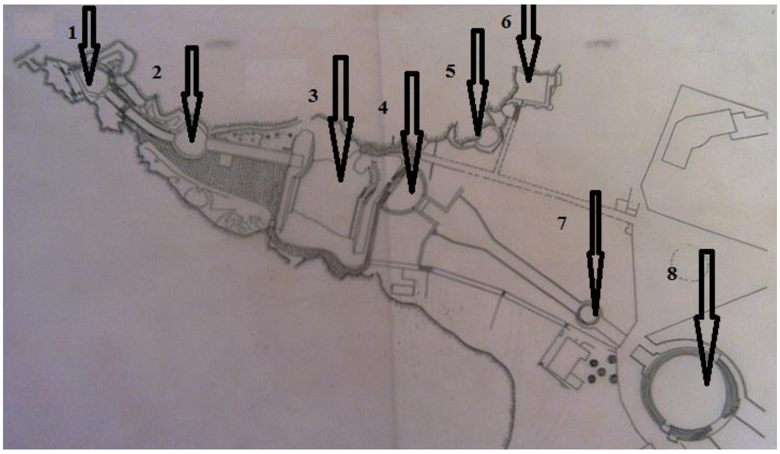

Figure 3: Layout of the Tawilah Cisterns

Figure 4: Catchment Area of the Cisterns Including the Conducting Channel

3. Morocco

Survey Results

The khattaras represent, beside rainfall, a major source for drinking water and irrigation in the Tafilalet area, especially since the years 2008–2009, which were years of great drought as well as dramatic floods.

The respondents, in their majority, favored construction of walls to protect the khattaras against destruction, especially during floods. They also want general protections against desertification. Almost all respondents thought floods and drought added to desertification and threatened the khattaras.

Others threats to the khattaras are an ageing population and the migration of young people to other areas of Morocco or abroad.

Respondents also cited the recent appearance of very big farms, which have the resources to irrigate by drawing water from very deep underground. This depletes the water that feeds the khattaras.

The great majority of respondents recognize the importence of protect the khattaras and keeping them operational. If nothing is done quickly by the local authorities and the khattaras dry up, families will lose their livelihoods and incomes, forcing them to move to other areas of Morocco or abroad.

Technical Parameters

The quality of water is measured by the following means:

- The taste of water
- Incidence of disease related to water consumption

There is no public control on water quality. But people trust water that they extract from the network of khattaras or/and wells. In case of doubt, people boil water. The general understanding is that if there is no residue in the kettles, quaity is fine.

Wells that had been dug by ONEP (National Office of Drinking Water), were believed to contain poor-quality, contaminated water. But that is due more to nonfounded rumour, since no scientific study was conducted to arrive to such a result.

Overall, water extracted from the Khattaras is of a high quality. Water extracted from wells needs to be boiled before domestic use, but is of sufficent quality for irrigation

V. LINKAGES BETWEEN CASE STUDIES

Some general trends and features can be observed throughout these different cases:

- The communities in the three case studies rely on groundwater or rainwater for irrigation, but they have different distrubtion systems – wells, pipelines, or canals.
- The main field work results show a great similarity between case studies regarding basic water-supply problems.
- In the three areas, the availability of water is subjected to several threats: floods (increasingly frequent and strong), droughts (also very hard in certain years), sandstorms, and the advance of the desert. Climate change seems already at work, and it's making the problem of water scarcity for the concerned populations increasingly difficult.
- To these very great natural difficulties, there is a lack of available means, including funding the administration should mobilize to reduce the effects of the above risks. It is necessary to also mention the underdevelopment of our populations and the obstacles, including lack of institutional capacity, faced in organizing a coherent action against water challenges in our areas.
- In all of the three cases, uncertainties are an issue at some point in the analysis. Either the uncertainities are so wide that they are unmanageable from a quantitative point of view, or at the very least they require advanced simulations techniques. This is especially the case with climate variablesIndeed climate modellingoften requires quantitative machinery (complex systems). In this situation either more research is needed or resorting to simplifications, that give a valuable yet possibly weakened argument.
- In all three sites there is a case that can be built at least qualitatively for significant losses associated with climate change. The uncertainty of these losses makes them by definition a risk.
- In all three sites, but to various extents, vulnerability and exposure to climate change are very high, making specific groups critically at risk.

VI. CONCLUSIONS

This report investigates the rehabilitation of water distribution systems as an adaptation to climate change at three different sites: the Yarmouk-Decapolis Tunnel in Jordan, the Tawilah Cisterns complex in Yemen, and the khettara network in Tafilalet, Morocco. Climate change effects will become more apparent and tangible over the long run. At the same time, as we look further ahead, we see ever-increasing uncertainties. This report discusses the vast amount of data that was mined in an effort to get the clearest view feasible. The essentials findings in each of the three sites are summarized below.

Jordan: Yarmouk-Decapolis Tunnel

Many portions of the Yarmouk-Decapolis Tunnel are still in excellent to very good condition, with little damage, and contain relatively large amounts of good-quality water. These segments, which extend from one to 10 km, are used for irrigation by local farmers. The water level in the tunnel ranges from 40 cm up to one m. The tunnel is an important source of water, and can help remedy the water shortages in the area and adapt to climate change.
The followings are the main conclusions of this study:
Conclusion
1-Yarmouk-Decaplois Water tunnel is the longest yet reported underground tunnel in the World. It occurs in the northern Jordan and extends between the towns of Al-Tura and Um Qais (Gadra), with total length of 140 km.

2- The tunnel is considered as an ancient-system developed for collecting and storage water to improve their live. The Roman constructed two over ground canals from southern Syria to bring water over considerable distance (about 60 km long canal) to the tunnel.

3- The tunnel illustrates the ingenious measures inhabitants of the area developed to assure their survival throughout the course of history.

4- The tunnel systems was constructed to direct water to five Decapolis cities, Garda (um Qais), Abila (Quweilbeh), Capitolias (Beit Ras) and Arabila (Irbid).

5- Several segments of the tunnel are in a good structure situation.

6- This study gives a detailed survey of a selected segment of Yarmouk Decapolis tunnel system (Hobras –Abila).

5- Water is collecting nowadays in the tunnel from infiltration from water table and local spring's rain fall shallow water aquifers along the extension of the tunnel.

7- The tunnel in the studied segment contains water level that ranges from several centimeters up to one mete.

8- The studied segment of the tunnel serves water supply for the locals by means of interconnected network canals to provide irrigation water.

9- The water from the local springs is not able to satisfy the need of local's elements.

10- The present situation of water supply condition is generalized as shortage in summer and surplus in winter.

9- Selected water analyses collected from springs show that the water is of good quality and can be used for drinking, irrigation and other domestic uses and matches the WHO standards.

10- Currently, the water collected inside the tunnel is used for different purposes (e.g. for irrigation and horticulture as well as for drinking water).
11- It is important to point out that the importance of the tunnel for water management in Jordan and help in people settling throughout history as well as overcome water shortage due to different natural climate and environment conditions.

12- Investigation of the ancient water storage systems such as the Yarmouk-Decapolis water-tunnel and finding suitable ways to introduce modern technologies in order to put these systems into use again which are importance to overcome water shortage in Jordan.

Yemen: Tawilah Cisterns complex

Cistern system serves as flood detention and rain water harvesting facility. It helps ensuring safe disposal of the combined storm flow from the large barren rock upper Tawila catchment and the storm water flow from the urban area in the lower drainage sub-basin through the Tawila drainage Channel. It also provides reserve storage of drinking water used for irrigation and entertainment requirements of the Tawila Garden Park located in the Cisterns site and in emergency cases . The main conclusion are:

- Most of beneficiaries are not aware of the Cisterns and this reference of the local authority.
- The the main function of the Cisterns to be Flood protection and was very efficient protect the city from flash flood .
- The main reasons for system deterioration over time are lack of maintenance
- All penficaries agreed should be rehabilitated.
- Aden's residents are benefits from the Tawilah complex because the Cisterns are protect the city from flooding.
- the water quality from Cisterns is not enough for use for direct drinking, may be after simple treatment, while for agriculture purposes is enough quality.
- The management issues are the responsibility of local authorities
- the l labor is available for system operation and maintenanceand need better training and better pay as they come from underprivileged groups in nearby Governorates.
- the system needs a specialized local expertise in maintenance and rehabilitation, which has a traditional knowledge by using local building materials.
- From the chemical and bacteriological analysis all of the studied samples of Crater wells are not suitable for drinking use.

Morocco: Khettara network in Tafilalet

In the area where the field work has been leaded in Morocco, people and local responsible consider that the water management system can and has to be rehabilitated. This, because it's possible and it's absolutly necessary mainly for agriculture activity. They that this has to be done very quickly to avoid more damages on the still functionning Khattaras.
Population is ready to work on, and has some experience for leading the restoration/maintenance operations, but this needs logistical and financial help from governmental agencies and also technical support from those agents and also from international donor agencies.

In conclusion, the three sites are found to be at risk, calling for integration of adaptation strategies within the wider development planning of these areas. All systems are extremely serious and need to rehabilitate and renovate.

VII. RECOMMENDATIONS

Jordan:

1- Undertake rehabilitation and maintenance of the destroyed parts of the tunnel.
2- Increase public awareness via mass/social media, workshops, and conferences about the important of the tunnel.
3- Complete GPS cataloguing and documentation of the springs in the area of the tunnel in order to create and canal network for recharging the tunnel. Springs are surface water which originate from the tunnel.
4- Complete 3d modeling of the tunnel, including three-dimensional morphology of the tunnel and the surface topography
5- Determine and document the springs and artesian wells in the area along the tunnel.
6- Undertake detailed investigations of the digging methods of the tunnel (structural analyses).
7- Complete a material analysis (building materials, artifacts, mortar and plaster) for reconstruction purposes.
8- Environmental impact assessment (EIA) for the complete tunnel area.

Yemen:

- Improve conducting channel from the cisterns complex through the district (Crater) to the front bay by removing all obstructions (Al-Taweela valley).
- Reconstruct any manholes or any authorized building in storm water channel which causing obstruction.
- A telemetric or automatic rain gauge maintained at permanent metrological sites on the plateau of the upper Crater.
- Remove all rocks, stones and any sediments from catchment area of each dam to increase the quantity of water.
- The status of the flood protection system is extremely serious and needs to be rehabilitated and renovated.

Morocco:

- For the restoration and maintenance actions, there is a great need to organize a partnership between several agents and organizations which are already acting in the area. Local government agencies do not have many financial means, but can be useful in mobilization of the population and promoting awareness regarding the importance of khattaras. They can also help influence regional and national administrations (ORMVA – Office régional de mise en valeur agricole) to intervene in a more significant way on this level.

- Build a partnership with local government agencies to increase public awarness of the importance of khattarah restoration, and push regional and national administrations to place this issue as a priorty.
- Lead a technical field study (by local associations concerned with water and development issues as well as with scientists and experts) to determine which Khattaras can be restored and/or maintained.
- Call for meetings with administrations responsible for carrying out restoration and maintenance projects and involve them in this effort.
- Contact international agencies to elicit their technical and financial support.

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IX. ANNEX A – QUESTIONNAIRES

Jordan – Questionnaire Yarmouk Tunnel		
First name	Last name	Age
Education level	Marital status	Number of children
Profession	Gender	Date and location of interview

B-Yarmouk Decapolis Tunnel	
What do you use water for? (household needs, commercial agriculture, subsistence agriculture, other)	Yes No occasionally
Do you benefit from the Decapolis Water Tunnel System in any way or know someone who does? In what way?	
Are the amounts of water in the tunnel is enough for your irrigation?	Yes No occasionally
What is the used irrigation water quantity (m^3)?	
Is the quality of water in the tunnel suitable for irrigation? If no, why not?	
Are the distances between the tunnel & irrigated area far?	Yes No
Are the surface channels that bring water from the tunnel to the irrigated area adequate?	Yes No occasionally
Do you think tunnel rehabilitation feasible? Why/why not?	
Do you think the current situation of the tunnel is suitable for water harvesting?	Yes No
What do you think are the main reasons for the tunnel's deterioration over time?	
Who is responsible for management including operation and maintenance of the Yarmouk – Decapolis Water Tunnel? (local authorities, local communities, private sector, etc.)	
Is the expertise and labor needed to maintain the tunnel readily available?	
C-Crops	
What are the main types of planted crops?	
What is the size of the irrigated area?	
D- Local irrigation	
Do you use other water resources for irrigation (springs, wells, etc.), if yes, pls., specify the sources type?	
Do you use municipal water sources in the area in addition to the water from the tunnel?	Yes No occasionally
Do you make regular maintenance for the water system safety? If no, why not?	
E- Irrigation Water	
Are you practicing rainwater collection and use?	Yes No
Do you store (partially or completely) the water you get from the tunnel?	
The total amount of annually collected water (m^3)?	
Do you pay for the water you use from the tunnel?	Yes No
Are you aware of the water pollution problems?	Yes No

Yemen - Questionnaire Tawilah Cisterns

1/ Place – area:

Location of Interview:
Date of Interview:
Name of surveyed person or institutions :
Sex :
Age :
Educational level :
Profession / activity:

2/ Land - surface and storage

What are the main uses of the Tawilah Cisterns?
How much is the storage capacity of cisterns?
How much is the protected area?
How much is the irrigated area:
Origin of the water of irrigation:
Part (%) from the Cisterns :
Part (%) from the wells :
Other sources :
Main Crops :

3/

Situation of Cisterns:
are they operating efficiently ? Yes no
are they operating partially? Yes no
They don't operate ? why ?
Do you take part in the maintenance of the Cisterns?
Never
Often
Who is the responsible for O & M of the Cisterns?
What can be the role of NGO's in O & M of the Cisterns?
What can be the role of individuals
Is the needed expertise and labor needed for daily operation and maintenance available?
If no, why?
If yes, where does the needed labor come from? (local communities, certain demographic groups, other towns, etc.)

4/Flood and water Problems :

Are you aware of the Flood problems?
Do you feel that the Cisterns protect the city from floods? Yes no
When was the last Flood?
What are the efficiencies of the Cisterns to protect the city from Flood?
What are the efficiencies of the Cisterns for water harvesting and storage?
What are the efficiencies of the Cisterns for Recharge?
Do you know that water level is dropping very quickly in the wells?
What do you think has caused the problems?
Do you think the problems are getting worse with time?
Is the system can be the alternative sources for drinking and domestic use?
Do you think the Cisterns should be rehabilitated? Why or why not?

5. /Water Quality Problems

What do you use water for? (household needs, commercial agriculture, subsistence agriculture, other)
What is the water demand or consumption in surrounding area?
Is local water supply sufficient?
Where do you get your water? (pipelines, wells, tanks, etc.)
What is the quality of water in the Cisterns?
What is the quality of water in the wells?
Are you aware of the Pollution problems? Yes no

What do you think has caused the problems?
Do you benefit from the Cisterns in any way or know someone who does?

6./. Management Issues

6-1 **Local organization and cooperation.**

How do normally rehabilitate the systems?
What kind of rehabilitation?
What kind of building material is used by system?
Do you have any knowledge about the maintenance?
Is there any cooperation in such issues? Which?
Has this cooperation worked so far?
Do you think a better arrangement is required because the breakdowns of the systems problems are becoming more critical?
Any suggestions on HOW and WHO should make such arrangement?
Do you think the government should play a role in this regard? How?

6.2 **Government Role**

Did you or the organization as a whole approach the any government body for solutions? Which?
Do you know think the Government should decide who will rehabilitate and for what?
Who do you think should officially represent you in discussing the O& M issues with Government officials?
Who do you think should officially represent you in discussing the rehabilitations issues with Government officials?
Do you know which Government body is responsible for the management of the system?

Morocco - Questionnaire Khettaras

Question 1. Place
Location of interview:
Date of Interview :
Question 2. ID of the surveyed person
Name :
First name :
Sex :
Age :
Educational level :
Marital status :
Number of children : Children under 18
Dependent persons (people living in the same house, under the same roof) :
Profession / activity :

Question 3. Land - surface
What is the percent of irrigated land?
What is the origin of the water for irrigation?
How much water is needed for irrigation?
Is local water supply sufficient?
What is the Part (%) coming from Khettara:
What are the other sources for irrigation water?
What are the main cultures :
During which period of the year :
Produced Quantities (during the last two years) :
Subsistence farming (production for oneself) :

Production oriented to the market (Quantity and value) :
Local market (part - %) :
National market (part - %) :

Question 4. What is the situation of khettaras :
a/ they are operating normally
b/ they are operating partially
c/ They don't operate :
If c or b, why?
Since when?
What are the main water problems encountered during the last 5 years?
Is the quality of water produced high enough for use in agriculture ?
Why or why not ?
Do you benefit from the khettaras in any way or know someone who does?
How effective do you think the system is?
Do you think the khettaras should be rehabilitated? Why or why not?
Do you contribute to the control of distributed water :
Do you pay for provided water :
If Yes, at which price (m3) :

Question 5. Who is responsible for the maintenance of the Khettaras?
Do you take part to the maintenance of Khettaras ?
a/ Never :
b/ Often :
c/ When it is necessary / you're asked to :
Is the needed expertise and labor needed for daily operation and maintenance available?
If no, why?
If yes, where does the needed labor come from? (local communities, certain demographic groups, other towns, etc.)

Question 6. According to you, how one can guarantee the durability of Khettaras in the region :
In which framework :
What can be the role of state in this matter :
What can be the role of NGO's (like yours) :
What can be the role of individuals :