The crisis facing Tunisian drainage tunnels: identification, analysis and evaluation of water heritage in the Mediterranean region

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ABSTRACT

In regions with Mediterranean and steppe climates, the presence of surface water is sporadic, and a unique – but fragile and undervalued – element of water capture for irrigation and human supply is the ‘qanats’, ‘foggaras’, ‘mkoulas’ or water tunnels. The central objective of this project has been the full study of Tunisia’s drainage tunnels. The inventory, analysis and heritage evaluation of Tunisia’s ‘qanats’ have been possible through the application of a particular methodology during four annual sessions of fieldwork and analysis in the geographic information system (GIS) laboratory. The results have been: the creation of a spatial data and cartography infrastructure for the Tunisian ‘qanats’ and related irrigation systems; the identification of drainage tunnels; the typological classification of the water tunnels according to their morphological and structural framework; analysis of conservation status and intended water use; the implementation of a multi-criteria evaluation method with regard to the heritage quality of the ‘qanats’; and finally an analysis of the landscape relationships between ‘qanats’ and oases.

Key words | evaluation method, mediterranean water heritage, mkoula oasis, qanat, Tunisia

INTRODUCTION AND OBJECTIVES

The drainage tunnels for the collection of subterranean and sub-riverbed water – known as ‘mkoulas’ or ‘aín’ in Tunisia – stand as excellent references for water heritage in the countries of North Africa. The use and control of water has resulted in the modification of the natural environment. It has given rise to systems of human settlement and also irrigation; a set of traditional artefacts and knowledge rich in environmental and heritage value, which through centuries have been capable of producing cultural landscapes and, on occasion, of combating desertification (Laureano 2005).

For the traditional exploitation of water resources, Tunisian societies have used diverse collection methods, based on the environmental and climatic conditions (El Amami 1984). In general, we can highlight the exploitation of mountain lake water in the north-west of Tunisia; the terrace zones in Le Kef, Siliana, Zaghouan and the central Dorsal foothills; the flash floods of the ‘oueds’ in Kasserine, Sidi Bouzid and Kairouan; the high density surface-level wells in the coastal areas between Tunis and Mahdia; the area of Meskat in el Sahel (Sousse, Monastir …); the territory of Jessours, on the Gafsa–Medenine–Tataouine strip; and finally the area of cisterns in Sfax and Djerba (El Amami 1984; Henia 2008). However, the implementation of colonial and postcolonial agricultural policies and the loss of water control by the local population have had environmental and social consequences. Traditional irrigation systems and their users are constantly adapting to new situations and diversifying their practices (Battesti 2012).

One particular aspect of water storage linked to urban settlement and to irrigation systems is drainage tunnels. These tunnels form a system of traditional subterranean...
and sub-riverbed water collection, documented since the 7th century BC. They are widespread throughout the Mediterranean basin and are better recognised internationally by the term ‘qanat’ (Goblot 1979; Lightfoot 2000). The use of this technique brings a series of strong advantages despite the initial difficulties which come with their construction. On the one hand, the collection and transportation of water underground in an arid environment prevents the loss of water through evaporation, which would be high in the case of channelling water in canals above ground (Wessels 2012). On the other hand, the flow of water from the interior lands is practically horizontal given the minimal slope and the forces of gravity, meaning the avoidance of using energy that would be needed in the case of vertical wells.

In recent years some major projects have been undertaken that permit the study of Spanish and Tunisian drainage tunnels from a territorial point of view, in collaboration with the Institute for Arid Areas of Médénine (Hermosilla 2006; Hermosilla & Moussa 2010). These projects include the European Commission Project (Incomed Programme) Foggara Inventory, Analysis and Evaluation of Traditional Water Techniques of European and Saharan Drainage Tunnels (2003–6) and a project financed by the Spanish Agency for International Development Cooperation (AECID) called The Mediterranean Studies Centre of Drainage Tunnels and Associated Landscapes of Tunisia (2010–13). This work has been complemented by various studies between 2007 and 2010 within the framework of the Interuniversity Programme of the Spanish AECID, the outcome of which was the characterisation and valuation of drainage tunnels from a landscape and heritage perspective. Note that before initiating these research activities, studies on Tunisian drainage tunnels as cultural heritage were scarce and the interest of Tunisian authorities was practically non-existent.

In the past 40 years, numerous ‘mkoulas’ have ceased to be functional. There are different views on what caused the collapse: climate change, overexploited aquifers by pumping stations or lack of institutional management. In any case, the consequence has been a rapid deterioration of these ancient structures and the intangible culture linked to them. Therefore, it is necessary to find strategies for these deteriorated drainage tunnels and the preservation of water culture. Some authors have suggested integrating the drainage tunnels into town planning (Sors 2005). Others propose management by local institutions to resurrect the drainage tunnels (El Faiz & Ruf 2010). However it is not possible to make decisions without an adequate knowledge of the topic (El Faiz 2012).

For this reason, the central objective of this investigation is the identification, characterisation and spatial analysis of the Tunisian drainage tunnels and their impact on aspects of landscape and heritage. Among the specific objectives, we highlight the following:

- Inventory, typological study and mapping of the Tunisian drainage tunnels.
- Analysis of the use and management of water collected by means of drainage tunnels.
- Evaluation of the heritage quality of the inventoried tunnels, using a specially designed multi-criteria analysis system.
- Analysis of the relationship between drainage tunnels and water landscapes, in particular oases.

**METHODS**

The investigation has made use of an ad hoc methodology, designed for the study of Spanish drainage tunnels (Hermosilla 2008) and whose application to Tunisia has proved satisfactory. The methodology is based on four main consecutive phases (Figure 1). The crisis facing the Tunisian drainage tunnels has been identified by interdisciplinary diagnosis. Different viewpoints are needed in this kind of research due to environmental, economic, cultural and social dimensions that water heritage (and drainage tunnels in particular) have.

The development of the methodology is detailed step-by-step by following the sequence of each phase shown in Figure 1.

**Phase 1: inventory**

This phase identifies and geographically locates the drainage tunnels, and subsequently includes them in a spatial data...
infrastructure using geographical information system software, which allows us to organise and manage the information and to produce detailed mapping. In order to identify the tunnels, the task of collecting bibliographic and documentary sources for the whole Tunisian territory was undertaken. The participation of local agents was also important for obtaining information. Likewise, four periods of extensive fieldwork, from 2010 to 2013, were undertaken over the entirety of the area where tunnels were identified.

**Phase 2: analysis**

Each tunnel was studied holistically in relation to its geographic, physical and human contexts, as well as to its morphological and functional characteristics. The time spent studying each tunnel ranged between 1 and 3 days, depending on factors such as accessibility of the interior of the gallery or the complexity of the irrigation system resulting.

Analysis was undertaken on the construction techniques used, the constituent parts of the tunnels, the maintenance work carried out, the use of the tunnels and the conservation status. All this allowed the creation of a typological classification of the tunnels. Finally an analysis was also made of the resulting water landscape – a by-product of the designed hydraulic structures and of the human activities linked to them: agricultural irrigation and population settlements. Fieldwork was carried out by a team of four researchers from the University of Valencia and the Institute for Arid Areas of Médénine.

**Phase 3: evaluation**

This phase perfects the analysis of the tunnels in as far as it incorporates complementary information concerning water heritage. Understanding the landscape-heritage value of the Tunisian drainage tunnels is essential for making decisions in the framework of policies that underpin water heritage.

The developed evaluation method is one of the so-called indirect methods of evaluation (Recatalá & Sánchez 1996). (Cultural and landscape heritage evaluation methods can be differentiated into: direct methods – those in which the cultural or landscape value derives from perception of technique and is not composed of components or criteria; indirect methods – those in which the value is obtained from measuring the value of distinct components or criteria; and mixed methods – which evaluate by combining both types with the aim of integrating them.) It concerns a multi-criteria evaluation method based on those principles which allow for the definition and assessment of cultural heritage. Literature reviews (The Burra Charter 2000; Natural England 2008) and our own experience have led us to select 10 evaluation criteria. The method assesses criteria-fulfilment by each tunnel with the value of 1 point. Thus, the final value of each tunnel will be the result of adding up all the points obtained through the fulfilment (or not) of the 10 fixed criteria.

The designation of values from 0 to 1 is arbitrary (Hobbs 1985; Recatalá & Sánchez 2001), and as such the final result does not hold a strict mathematical significance, given that it is not easy to define the exact mathematical relationship between some cultural or environmental parameters. Nevertheless, it does permit us to obtain some results to categorise in a hierarchy and to compare the inventoried tunnels. According to the resulting value, it also allows us to decide on the type of action point that each tunnel needs.
We have established a hierarchy with five categories. In this way, if the obtained score of a tunnel is between 0 and 2 points that tunnel is not considered to be of landscape-heritage interest. If the score is between 3 and 4 points, it is considered to be of low interest; between 5 and 6 points, of average interest; between 7 and 8 points, of high interest; and between 9 and 10 points, of very high interest. The chosen criteria are as follows:

- Representativeness of the tunnel with regard to its type of construction.
- Significance: the importance of the tunnel in shaping the local water culture.
- Tunnel integrity. For this we have considered the degree to which renovations and alterations to the system have been loyal to the original tunnel design and nature.
- Conservation status, related to operational status. The conservation of the tunnel, its functioning and the conservation of the system have been assessed.
- Age of the tunnel. They are considered ancient if they are more than a century old.
- Cultural recognition by local societies. We have considered if local societies are aware of the mkoulas and if they identify with them.
- Technological value of the tunnel. We have chosen to consider aspects such as the technical engineering used to solve design problems with the tunnels, levelling techniques or improvements to innovation in water-use techniques.
- Artistic value of the tunnel. For this we have considered the design of the hydraulic system as well as the protection measures taken.
- Geographic and landscape context, for which we have considered harmony with the environment or the degree of visibility of some of the constituent parts of the tunnels.
- Identity of traditional irrigation systems or urban settlements fed by the tunnels. We have considered the identity of such systems, both in their hydraulic condition and in their relationship with the surrounding area.
- Societal consideration of the tunnels. As indicators we have used investment by public administrations and public–private partnerships, their inclusion on cultural and tourist maps or routes, or documentary material in circulation, both written and audio-visual.

Phase 4: prescription

Based on the analysis and evaluation, the objective of this last phase is to settle on action points for the drainage tunnels and their geographical context. The action points are classified into passive actions – aimed at regulating the protection and use of enclaves established because of the drainage tunnels; and into active actions, direct action of renovating the tunnels and restoration of the associated water landscapes (Pascual et al. 2002).

RESULTS AND DISCUSSION

Identification and classification of the drainage tunnels

The study has made possible the inventory and classification of the tunnels, recording their morphological and functional characteristics on file, which together form part of the Tunisian drainage tunnel inventory. The classification of the Tunisian tunnels has, among other results, made it possible to establish comparisons between each one, based on their particular characteristics and the region in question.

After literary review and fieldwork, 125 drainage tunnels were identified, distributed in an irregular pattern throughout the country. They are located mainly in the southern governorates of Tozeur (11 tunnels), Gafsa-El Guettar (31) and Kebili (43), around Chott el Djerid and Chott el Guettar; and in the interior governorates of Kasserine-Sidi Bouzid (10) and Le Kef (5), on the edge of the Tunisian Dorsal range. The rest appear in certain places in the Medjera river valley (one in the upper stretches in Jendouba; four in the middle stretches in Béja); on the coast, as in Bizerte (6), Tunis (2) and Sousse (1); and in the places between, such as Zaghouan (4), Kairouan (3) and Gabès (2). There are few tunnels in the humid areas, with rainfall above 700 mm (Table 1). In sub-humid areas, with rainfall between 600 and 400 mm, there is hardly any evidence of this type of water resource collection – only six tunnels. In the strip of land where rainfall is between 400 and 600 mm, 12 tunnels were discovered.

Most of the tunnels – more than 80% – were pinpointed where rainfall is below 400 mm (Figure 2). In this area, the concentration around Kasserine stands out, with 10 tunnels
in areas of rainfall between 200 and 400 mm. Where rainfall is between 100 and 200 mm, we found the largest quantity, with 85 tunnels (68% of the total). In short, the 125 tunnels are distributed unevenly depending on the regional climate: in the north, with a Mediterranean climate and wet season there are 22 tunnels; in the central areas, characterised by a Mediterranean climate with arid features, there are 52 tunnels; and in the Saharan desert climate with Mediterranean features, there are 53 tunnels.

The classification of the Tunisian drainage tunnels makes it possible to check the type of tunnel pinpointed, depending on: the construction techniques used (excavation via trenches or through tunnels, etc.); the natural environment where they are located (foothills, the banks of ‘oueds’, along the beds of ravines, etc.); the dimensions or the building material used (vertical or horizontal shafts, mother well, mine entrance, etc.); or the length to which they extend. The tunnels have been classified into eight types or classes. Table 2 summarises the number of tunnels catalogued according to their type.

Table 1: Tunisian climatic regions and drainage tunnels

<table>
<thead>
<tr>
<th>Climatic regions</th>
<th>Climatic areas</th>
<th>Tunnels</th>
<th>Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Mediterranean climate with wet season</td>
<td>1. Humid area</td>
<td>1</td>
<td>Close to Jendouba</td>
</tr>
<tr>
<td></td>
<td>2. Sub-humid area</td>
<td>15</td>
<td>Concentrated in Le Kef (5), Bizerte (6)</td>
</tr>
<tr>
<td></td>
<td>3. Semi-humid area</td>
<td>6</td>
<td>Zaghouan, Tunis</td>
</tr>
<tr>
<td>B. Mediterranean climate with arid features</td>
<td>1. Semi-arid area</td>
<td>4</td>
<td>Strip of land from Sousse, Kairouan, interior Kasserine</td>
</tr>
<tr>
<td></td>
<td>2. Sub-arid area</td>
<td>10</td>
<td>Interior Kasserine</td>
</tr>
<tr>
<td></td>
<td>3. Arid area</td>
<td>38</td>
<td>El Guettar (32), Gafsa (4)</td>
</tr>
<tr>
<td>C. Saharan desert climate with Mediterranean features</td>
<td></td>
<td>53</td>
<td>Around Chot El Djerid: Tozeur-Kebili-Douz</td>
</tr>
</tbody>
</table>

Three-quarters of the tunnels analysed in Tunisia are ‘qanats’ (Figure 3). The concentrations which stand out exist in Souk el Ahad and Mansoura, Dégueche and El Guettar. This is also the most common type in the northern area and they are located in areas of gentle gradient, far from mountain environments and plains. They rely on a mother well which allows for the positioning of an aquifer and the excavation of a tunnel with vertical shafts (Lambton 1989).

The ‘minas’ form the second most common type of tunnel; however, they only represent a tenth of the total number. They are usually situated in semi-mountainous areas. They are located at springs which surface in the area where they have been excavated, in a way which produces a decrease in the water table level or that requires an increase in the drained water flow (Ron 1995).

Finally, other tunnels fall into distinct types such as ‘zanjas’, ‘cimbras’ (Figure 4), ‘cimbras’ with horizontal shafts, ‘minas’ with vertical shafts, sub-riverbed dams and ‘cimbra–zanjas’. These tunnels can be broadly summarised as variations of the two main types (‘qanats’/‘minas’) (Hermosilla 2006, 2008).

A relationship between the length of the drainage tunnel and the type to which it belongs has been identified. The majority (~75%) measure between 100 and 1,000 m, where 48% are between 100 and 500 m and 27% are between 500 and 1,000 m. Of the remaining tunnels, 16% do not exceed 100 m, whereas 9% surpass 1,000 m. As mentioned, a relationship can be seen between the average length of the tunnels and their type. The ‘minas’ measure around 50 m (although there is a great variety in the lengths), the ‘qanats’ have an average length of 500 m and the ‘cimbras–zanjas’ exceed 700 m on average. A relationship can also be seen between the construction techniques, degree of complexity and measurements of the mines.

Functional nature and conservation status of the drainage tunnels

The Tunisian drainage tunnels have been traditionally characterised by some common uses, as much for settlements as for irrigation. In fact, the vast majority are used for both purposes, except the Ain Hdefa tunnel in Gabès, which, given the high salinity of the waters, supplied its flow to continental salt lakes. The balance which has existed
for decades (and in some cases for centuries) between the use of surface-level aquifers and the amount salvaged from the water table has become uneven.

The introduction of vertical catchment – the wells – backed up by the Tunisian government’s water policy, has resulted in an accelerated abandonment of the drainage tunnels throughout the Tunisian territory. Urban growth, motivated by rural exodus and town-planning policies, has led not only to disuse, but also to the physical disappearance – in part, or in full – of many tunnels (Table 3).
These territorial processes have proved negative for the development of the tunnels and their functional nature (Figure 5). At present only 22 functional tunnels remain, whereas the other 103 are abandoned or destroyed. Considerable regional differences can be noted. In the central-northern area around 50% of the existing tunnels are functional (19 of the 36 identified), linked to urban settlements. The non-functioning tunnels have suffered the consequences of overexploitation of other capture systems – in particular wells – and urban expansion. This is the case in Aïn Oued Kharroub, in Sousse, where the section closest to the mine entrance has disappeared due to urban expansion of the capital city, and also in Aín Bir el-Adine, a tunnel in Kairouan, which despite its long history no longer flows due to the opening of wells.

The outlook in the southern areas is different, with only three active tunnels out of more than 100 which were once in operation. However, 85% of the irrigated land associated with these drainage tunnel systems remains active, but only 3.4% corresponds to the water flow obtained from the tunnels which still remain in operation. More than 80% of the irrigated land within the scope of the drainage tunnels remains functional thanks to the construction of open wells since the 1960s, after state intervention, as a response to population increase, infrastructure policies and an agricultural boost. These bore holes provoked the exhaustion of the surface water table from which the tunnels drew their supply.

<table>
<thead>
<tr>
<th>Type of tunnels</th>
<th>Number of tunnels</th>
<th>Percentage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Qanat</td>
<td>97</td>
<td>77.6</td>
</tr>
<tr>
<td>Mina</td>
<td>13</td>
<td>10.4</td>
</tr>
<tr>
<td>Zanja</td>
<td>3</td>
<td>2.4</td>
</tr>
<tr>
<td>Cimbra</td>
<td>3</td>
<td>2.4</td>
</tr>
<tr>
<td>Cimbra with horizontal shafts</td>
<td>4</td>
<td>3.2</td>
</tr>
<tr>
<td>Mina with vertical shafts</td>
<td>3</td>
<td>2.4</td>
</tr>
<tr>
<td>Sub-riverbed dam</td>
<td>1</td>
<td>0.8</td>
</tr>
<tr>
<td>Cimbra-zanja</td>
<td>1</td>
<td>0.8</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>125</strong></td>
<td><strong>100</strong></td>
</tr>
</tbody>
</table>

![Figure 3](Qanat Ain Bousoufa, Oasis El Guettar.)
As Table 4 demonstrates, the results of applying the indirect evaluation method have proved illustrative of the present situation. In the northern governorates, the tunnels with definite heritage value represent 40% of the tunnels. Just under 20% of the tunnels have an average heritage value, whereas a quarter stand out precisely for their significance. It is worth noting that the architectural complex of the Temple of Water in Zaghouan is the most outstanding, achieving the maximum score of 10 points.

The tunnels of the central governorates, between the south of the Dorsal range and Sahel, stand out for their high heritage value despite their low number. They tend to be capture systems of Roman origin, with a certain degree of conservation (Gauckler 1897–1912; Solignac 1952; Mahfoudh et al. 2004). In the southern governorates, the heritage significance scored was less spectacular. Of the 89 tunnels analysed, only six obtained a value higher than 7 points, and the average value of the whole only reached 2.6 points (while in the central sector the average is 6.7 points). Despite the fact these tunnels were built in the 18th, 19th and 20th centuries, they permitted the creation of settlements, and the shaping of some unique landscape features: oases.

Establishing this evaluation method, together with the previous classification, provides us with information in order to take decisions about which tunnels need action, and how. The analysis has allowed us to confirm the importance of certain groups of tunnels in the central and southern parts of Tunisia (Figure 6). Here, the tunnels form part of the landscape by means of their vertical shafts or their effect on the use of water sources (agricultural irrigation and population settlement).

The action points proposed take various directions. First, we urge a deeper analysis to expand the knowledge of Tunisian drainage tunnels and their heritage and landscape significance. Another action point is the promotion of awareness among the population and the authorities with respect to these elements of water heritage. Greater social awareness would urge the governorates to propose...
measures for the protection and management of cultural and landscape heritage. Finally, we propose the recovery of the tunnels, or collection of tunnels, with the best landscape-heritage evaluation. This is the case for the Aín Boussoufa tunnel in El Guettar. A partial process of renovation has begun on this ‘mkoula’, having been recognised in the design of a cultural-touristic itinerary drawn up through a joint initiative of the University of Valencia, the Institute for Arid Areas of Médénine and the Association for the Protection of the Medina de El Guettar.
‘Qanat’ and oasis: cultural water landscapes

In Tunisia, with its aridity, survival is difficult for plant life, agricultural practices and human settlements. Yet the extraordinary contribution of water and humidity through traditional knowledge and hydraulic technology has made possible the presence of cultivated plantations (fertile low-lands around some ‘oueds’ and oases) – cultural water landscapes where water is a visible or underlying resource which defines the land and determines its future.
Oases constitute the most symbolic landscapes of arid and semi-arid regions. They are an excellent example of cultural landscape. Distinct types of oasis have been observed, depending on the morphology of the land and the type of water capture. However, in each type diverse strategies of water collection can be linked: principally wells, drainage tunnels and sluices. In Tunisia, we can distinguish various types of oasis, but work undertaken in recent years allows us to verify that it is the ‘sebeka’ oases (around endorheic depressions) where drainage tunnels (‘mkoulas’ or ‘qanats’) are the key elements. The palm groves in the oases at Tozeur, Degueche, Gafsa or El Guettar are excellent examples. About 53 drainage tunnels have been located at the oases in the north-east and east of Chott el Djerid and another 36 in the oases of Gafsa and El Guettar.

CONCLUSIONS

The development of settlements and productive spaces in areas with water deficit highlights the significant role played in Tunisia by ancestral know-how in water management. This know-how is reflected in the landscape and diversity of water structures and hydraulic systems. However, technological advances have changed the significance and role of water structures. In the past, Tunisian drainage tunnels played a significant role in land organisation, influencing population settlements and activity in the area, and spreading systems of agricultural irrigation. However, our investigation has allowed us to confirm that the present scenario of the Tunisian drainage tunnels is complex and critical. And this is motivated by external processes, far removed from the dynamic tradition of these water capture systems.

More than half of inventoried ‘mkoulas’ have disappeared or their conservation status is poor. Although there are different explanations for the cause of the ‘mkoulas’ collapse, it is the decline of the water table through drilling and pumping stations that is the most obvious. This process begins with the transfer of control over the water from local to colonial and then national elites (Battesti 2012) and it has environmental, social and cultural consequences. The first is the springs’ disconnection from the aquifer. The second is the conflict over water resource between the government and the local users. And the third is the accelerated deterioration of drainage tunnels and hydraulic systems.

The crisis facing the Tunisian drainage tunnels has been marked by interdisciplinary diagnosis which, for the first time, has covered the entirety of the Tunisian territory. The extent reached by the ‘mkoulas’ in the past has been verified, as well as their major significance in some Tunisian regions (oases), especially located in central parts (Kasserine, Gafsa, and Tozeur y Kebili) where the climate has arid features. This distribution of drainage tunnels’ confirms the observations of El Amami (1984) who said that, depending on the climatic region, the types of hydraulic devices are different to reach the scarce water.

A large part of the oases – water landscapes whose origins lie in the drainage tunnels – are in a critical situation. Rural exodus has meant the abandonment of some agricultural practices from these sources of production. The introduction of water capture techniques through motorised vertical wells has been progressively exhausting surface-level aquifers and with it has brought the functional use of the drainage tunnels to a standstill. Paradoxically, this state of abandonment contrasts with the heritage values which a considerable proportion of the tunnels still possess. The undertaken evaluation is, in this sense, quite enlightening: more than 15% of the tunnels hold high or very high heritage interest, and a further 18% are of average interest. However, it is clear that there is neither awareness on the part of society, nor the Tunisian authorities, of the cultural and heritage value of these elements of traditional water architecture. A lack of awareness is evident, and in consequence a lack of interest exists for this heritage – a situation which is exacerbating the neglect from which a large part of the Tunisian drainage tunnels is suffering.

REFERENCES


