

# COMPARATIVE ANALYSIS OF DRAINAGE TUNNELS IN TUNISIA AND THE EASTERN AND SOUTHEASTERN SECTOR OF SPAIN. A METHOD FOR THE COLLECTION OF SUBTERRANEAN WATER IN THE MEDITERRANEAN REGION

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Drainage tunnels (also known as *qanat*, *foggara*, *karez*, *mkoula*, mine, *khettara*, *puquio*, etc.) are important references of the hydraulic heritage, due to their implementation in much of the world, as evidenced in the works of Wilkinson (1977), Goblot (1979), Lightfoot (1997) and Semsar Yazdi and Khaneiki (2010 and 2012). In the Mediterranean region, drainage tunnels are of great importance, since they exist in almost all countries, which is reflected in several studies on this topic.

This technique dates back centuries, since it is documented as far as the seventh century B.C. The galleries are horizontal tunnels dug beneath Earth's surface in order to capture and extract the water from the groundwater so that it flow outwards under the action of the gravitational force. These tunnels take advantage of the most superficial subterranean aquifers by draining the groundwater, without overexploiting the water reserves of the aquifer. In the Mediterranean climatic domain, the population settled there must be adapted to the conditions of aridity or semi aridity, and thus the importance that drainage tunnels acquire to supply population centres and traditional irrigation systems.

The tunnels and their associated irrigation systems are factors of landscape creation and are part of hydraulic heritage. The hydraulic systems derived from the tunnels have a patrimonial value that goes beyond the work itself, because through them, cultural landscapes are built, which are constituted as elements of identity for the territories.

The main objective of this article is the identification, characterisation and comparative analysis of the Tunisian drainage tunnels, and the Eastern and South-Eastern sector of the Iberian Peninsula.

The area of study includes the entire Tunisian territory and, in Spain, the area formed by the demarcations of the Júcar and Segura Hydrographic Confederations, and the native river basins of the province of Almería, in what is the Eastern Mediterranean strip and the Southeastern strip of the Iberian Peninsula.

There are several environmental factors that can influence the location of the mines. The climatic factor determines the tunnels to be located where they are required, usually in places where there are no other strategies of water flow collection. The climate influences on the territorial distribution of the tunnels are, therefore, a large-scale conditions, since they usually act as a limiting and indirect factor. If we consider a more detailed scale of analysis, the geomorphological, topographical and hydrogeological factors have a greater influence on the concrete location of each mine. The water availability is a basic argument to explain the presence of tunnels. Hydrogeology determines on a small-scale each gallery and independently, since the mines are located where suitable conditions are given for the existence of an aquifer, in order to capture and transmit the water on the outside, according to the impermeable layer and the type of materials where it is excavated. Geomorphological factors and topography determine the design of the tunnels and their internal constructive characteristics (length, number of shafts, building materials...), which specifies the strategy they have to obtain the water flow.

In Tunisia, 70% of the mines are located below the 200 mm isohyet; it highlights the strip between 100 and 200 mm, with 59.2%. This distribution approximately corresponds with the traditional oases of the southern governorates. In the Eastern and Southeastern part of Spain, half of the abstraction is located in the isohyets between 200 and 400 mm.

In the bibliography there are not excessive classifications related to the different typologies of existing tunnels. The typological classification is an subject matter open, since by analyzing a greater number of galleries, the typologies and subtypes can be increased and modified. In most classifications, the main types are often detailed, and there's barely a mention of their variants. In the works carried out by the ESTEPA research group since 2004, we have made several classifications by combining different criteria, which leads to a wide typological variety of tunnels. In Antequera's thesis (2015), a classification essay, true heir of the previous ones, is elaborated, which constitutes the basis that we apply in this study. Our proposal of typology of tunnels is made based on three criteria: the origin of water abstracted; their constructive and functional characteristics; and the geographical environment they are located (mountain, interspaces and waterways and fluvial terraces).

In order to distinguish the origin of water abstracted, the tunnels are grouped into categories, according to the type of aquifer from which they are supplied: a) Groundwater; (B) Subterranean water and quaternary alluvial detrital waters; C) Mixed origin; D) Groundwater and surface water. In the Eastern and Southeastern part of the Iberian Peninsula, the correlation between the origin of water and the typologies is 94%, while in Tunisia it reaches 96% of the mines, therefore this classification is very effective.

The constructive and functional characteristics allow to set the types and subtypes of existing tunnels, since each one of them is defined according to the method of excavation

and the technical solution used for water flow collection. As a result of technological mixing, at the same tunnel may exist construction techniques corresponding to different typologies. The typologies and their constructive and functional characteristics are as follows:

- Mine: underground excavations from the deepening of a spring or upwelling.
- Mine with shafts: originated of an underground excavation from a source or upwelling and have one or two intermediate vertical shafts, but without a water well.
- Qanat without shafts: the origin of the abstraction consists of the underground excavation of a well until reaching the groundwater level. It does not have vertical shafts.
- Qanat: its origin consists of the construction of a well until reaching the aquifer. It is dug from the mine entrances to the water well. It has several vertical shafts.
- “Cimbra” and “cimbra with horizontal shafts”: they capture the subterranean water and/or detrital alluvial quaternary water and are usually placed in an environment of watercourses and fluvial terraces. The water infiltrates from the surface and enters through the roof of the abstraction and its gables. They have several vertical shafts or vents.
- “Zanja”: they do not use a mining technique of excavation, since the drilling of a ditch or a trench open-cast in alluvial less cohesive materials is enough. Subsequently, it is covered with slabs of flat stone and covered with the materials removed in the excavation. It does not have vertical shafts.
- “Cimbra”: it combines the excavation of an open-cast ditch with an underground excavation with mining techniques. It has several vertical shafts or vents.
- “Sub-riverbed dam”: this dam has a subterranean water reservoir located several meters deep with regard to the river bed. The tunnel is made by drilling a ditch in a trench, by open-cast. The water is captured through openings called putlog holes or loophole located on the front wall of the tunnel, which is the closest to the subsurface flow that flows through the watercourse. The opposite wall, which forms part of the reservoir, is waterproofed and lined with hydraulic lime to prevent leakage. In its layout there are several vertical shafts, but without a water well.
- Tunnels with horizontal shafts: they are usually located in a fluvial terrace environment, although in their construction they use only subterranean excavation techniques. They have several lateral shafts, since thanks to the thickness of the sediments of the fluvial terrace, is easier to reach the tunnel with a horizontal passage of a few meters, than with deeper vertical shafts.
- “Gallery-alcavón”: is an exceptional type of tunnel that takes advantage of a combination of subterranean water and surface water. It has no vertical shafts, but several lateral or horizontal. At the outside, it has a dam that provides an additional flow to the water abstraction.

The typology of the qanat is usually located in intermediate environments such as piedmont, glaciais and alluvial fans. It is the most abundant in the Spanish mines, where they represent more than a third of the total (36.9%), especially in the Tunisians, where it reaches 77.6%.

Mines, which are the most common type of tunnel in mountain environments, account for 28.9% of the Eastern and Southeastern part of the Iberian Peninsula, while in Tunisia it accounts for only 10.4%.

The group of tunnel typologies that usually locates in watercourses and fluvial terraces is composed of 77 mines in the Spanish sector and 12 in Tunisia, which supposes a 25.8% and 9.6% respectively. The most significant typology in these spaces is the one of the “cimbra” that represents the 17.4% in the tunnels analyzed in Spain.

The third complementary criterion of the classification of tunnels is the geographical environment where they are located. They are grouped into three major geomorphological environments: a) Mountain: including mountainside environments, mountainside base and platforms; B) Intermediate or transition: piedmont plains, glacis and alluvial fans; C) Watercourses and fluvial terraces: here are integrated river beds and fluvial terraces, thalwegs and ravines.

Not all the tunnels are located in a geographical environment that is assumed, according to their constructive and functional techniques, so in some cases they are decontextualized and outside the realm where they are usually found. The same tunnel can participate in two different geomorphological fields.

The basic parameter to measure the “environmental health” of a tunnel is the one that continues extracting the stream flow to the outside for its use. There are remarkable differences between Tunisian and Spanish tunnels. One of the most significant is the total number of tunnels with flow in both territories, as Tunisia barely reaches 17.6%, while in the area analyzed in Spain accounts for 70% of the water abstraction. In Tunisia, most of the mines are located around traditional oases, but the drilling by boreholes and newly created oases, which mobilize deep subterranean aquifers, lower significantly the piezometer level. In Southern Tunisia, only 3% of the mines continue to flow to the outside, which contrasts with the rest of the country’s tunnels, since of the remaining 36, 52.7% of them have stream flow.

In Spain, the loss of the functionality of tunnels reaches almost 30%. This hydric inefficiency has several causes: prolonged periods of drought; lack of proper maintenance that causes the collapse of some sectors of the capture; and the decline of the groundwater level. In Tunisia, nearly all of the mines are used as drinking water supplies, since this is the major role in obtaining stream flow. In Spain only 43% of the galleries are used as water supply.

In Spain 65.3% of the tunnels have an optimum or excellent state of conservation, whereas in Tunisia they only represent 17.1%. With a poor state of conservation, Spain holds 13.8% and in Tunisia this figure reaches 68.5%.

The drainage tunnels and their associated irrigation systems are seriously threatened. Traditional irrigation now suffers a structural crisis, which has repercussions in those tunnels that provide them with stream flow, as there are phenomena of abandonment and loss of functionality. Although the current viability of traditional irrigation is not assured, this type of groundwater abstraction has a very important heritage and landscape value. Drainage tunnels usually constitute a model of sustainability, an intelligent solution to obtain water without effort, by the force of gravity, after the initial hard work which represents its construction. The main threats to the tunnels are the loss of value of their main use and the massive reductions of aquifers. The tunnels take advantage of the shallowest underground

aquifers, they drain the underground water without overexploiting the aquifer reserves and use the subterranean water as a renewable resource. Despite these advantageous characteristics, there are several types of factors that negatively influence the crisis of the tunnels:

- A) Climatic and environmental factors: as a result of technological improvements in well drilling and drilling by boreholes, there is overexploitation or depletion of the most superficial aquifers (in Tunisian traditional oases only 3% of the tunnels conserve hydric functioning). There is a decrease in underground water levels due to the increase in temperatures in the last 50 years. The lack of water resources in most of the analyzed areas supposes a strong competition for water uses.
- B) Social and economic factors: the historical irrigations associated with the tunnels have a difficult expanding, being conditioned by the line of rigidity of the hydraulic space that marks the gravity. Due to their characteristics, the tunnels obtain a reduced stream flow in comparison with other methods of water abstraction, whether superficial or subterranean, which is why it is not possible to extend its irrigated perimeter. The other cause that contributes to the crisis of traditional irrigation are human activities, by introducing polluting substances that alter the quality of water and soil. Traditional irrigations associated with tunnels present important structural problems, which result is a deep crisis in farms. There are several processes that imply the volatility of agriculture as an economic sector: the atomization of property and smallholding; the aging farmers and the lack of generational replacement; the increase of the price of the soil; the disappearance of historical irrigation by changes in land use; and rural exodus and dwindling populations in rural areas.
- C) Patrimonial and landscape factors: the abandonment of the tunnels can cause their deterioration by lack of maintenance and cause cave-ins and collapses that stop the water circulation to the outside. The irrigated areas supplied by tunnels that have been progressively abandoned have a significant landscape importance, far superior to their current economic importance. Their abandonment implies the dismantling and fragmentation of the irrigated spaces, with the consequent environmental degradation and the loss of the structures of the traditional landscape.
- D) Political factors and public awareness: in both Spain and Tunisia there is a lack of awareness of the administrations regarding the cultural heritage of historical irrigation. Its cultural, ethnological and landscape value has been underestimated and even ignored in some cases. In addition, there is a lack of coordination between the different territorial and sectoral administrations. The society generally shows unawareness and a lack of interest in historical irrigation systems, since there is a lack of information and sensitivity. One factor that hampers the knowledge and the diffusion of the draining tunnels is its complicated way of make it heritage, since it is an “invisible patrimony”, being an infrastructure quite unknown for the greater part of the population.

Although there are differences between the Spanish and Tunisian tunnels, there is a single model of crisis, since most of the factors that cause it occur in both territories. In spite of

the current challenging situation, tunnels are a factor for the creation of cultural landscapes that have a high environmental value. The best way to sustain and preserve the cultural landscapes that tunnels have created is to keep them in operation and use them for the purpose for which they were designed.