Traditional Knowledge for a Sustainable Management of Water Resources:The "Cuniculi" Of Tuscania

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Abstract

Water management is today one of the most relevant issues across the world, and not only for developing countries or in areas affected by processes of desertification. In developed countries which are responsible for most part of freshwater consumption, the awareness about this concern drives towards the search for the best solutions and practices for a sustainable use of water. Modern technologies can help achieving this goal, but at the same time there is a lot to learn from past solutions that have proved to work on a long term basis. Etruscan cuniculi are underground water tunnels that were dug in bedrocks for land reclaiming, drainage or water collection. A research conducted in Tuscany – a region of central Italy- focused on both archaeological as well as functional aspects of cuniculi. Such a research was carried out by making comparisons between similar devices used in different countries across the Mediterranean area, the Middle East and Central Asia. The research pointed out not merely the various connections that cuniculi have due to man settling and land taming, but also the principles upon which these kind of devices are working in order to provide man with water, notably the increase of exchange surface between the underground and the surface ground, the gravity-driven movement of water and the combination of a multiplicity of small water sources like seeping or condensation.

The research has found out that density in the sample area is more than three times higher the figures reported in the specific literature and also brought up the numerous connections these kind of devices have, at present days, with the agricultural landscape which still function as infra-structures.

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The research also pointed out the great number of cuniculi which still today serve their ancestral goal they were dug for several centuries ago: something which seems to rely upon the continuous maintenance carried out across the ages by different populations and a great sign of sustainability resulting from these solutions. Starting from this great example of symbiosis between man and environment, the paper will talk about the extent the cuniculi today can represent a valuable tool for a sustainable water management and how the principles upon which they are inspired and work along can be a valid option even when planning and building 21st century water systems.

Keywords: *sustainable water resource management, Qanats foggaras, Cunicoli*

1. Introduction

Water management is today one of the most relevant issues across the world in order to contrast desertification process which is also involving wet countries due to global climate change as well as to spread awareness of a necessary sustainable use of water and of human activities.

In the UNCCD United Nations Convention to Combat Desertification, the process is defined as "land degradation in arid, semi-arid and dry sub humid areas resulting from various factors, including climate variation and human activities". Desertification (not to be confused with the transformation of land into desert) implies land degradation and the loss of soil fertility due, as for instance, to an accelerated soil erosion, or the influence of water scarcity is obviously relevant but the role of human activities (i.e. agricultural practices) must be carefully considered.

A particular attention in water management is not only required in developing countries; some Southern Italian regions are now interested, or will be in the closer future, interested by desertification process (Fig.1).

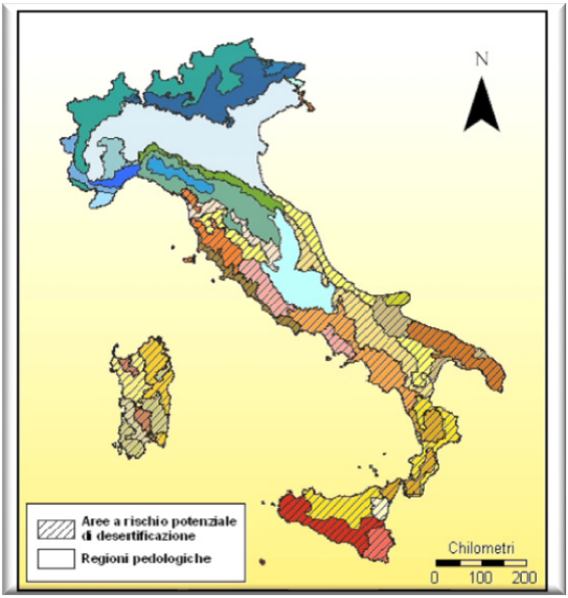

Fig. 1. Vulnerable areas to Land degradation and desertification

In rural regions of arid zones, promotion of sustainable management of land and rehabilitation of natural capital – soil in particular –, allows to improve resistance of agricultural, economic and social systems to climate change: in this sense, these actions are dealing with adaptation to climate change. Practical examples of this are measures developed within the framework of the UNCCD over the past 15 years which should be promoted as part of climate change adaptation:

- implementation of drought early-warning systems and risk prevention;
- integration of desertification risk and effects of drought into local and national policies;
- development of farming practices improving soil fertility, water retention aiming at guaranteeing crop growth and crops' availability;
- diversification of income sources: use of natural resources through appropriate channels, eco-tourism, etc.

Furthermore, the United Nations Millennium Development Goals, amongst its goals, consider a further support to the implementation of the United Nations Convention to Combat Desertification in those countries experiencing serious drought and/or desertification, particularly in Africa, through the international community's joint action in addressing the causes as well as desertification' s poverty impacts and land degradation in arid, semi-arid and dry sub-humid areas, consistent with articles 1, 2 and 3 of the Convention, taking into account ten-year strategic plan and framework aiming at enhancing the implementation of the Convention (2008-2018), supporting the exchange of best practices and lessons learned (including regional cooperation, mobilization of adequate and predictable financial resources).

Research and studies are quite abundant in the Northern Mediterranean basin, but they seem to be mostly addressed to the definition of indicators or to the production of methodology for the assessment of desertification risk rather than the production of useful results to land managers.

Problems connected with desertification processes are accentuated by an increased demand for water supply. During last decades, especially in developed countries, population growth and behavior's changes together with industrialization and agriculture intensification, have substantially modified and increased demand for water use. This is greatly relevant in agriculture and a more sustainable management of water arises is strongly needed.

In developing countries, instead, the arid middle East and North Africa, a similar phenomenon occurred and the scarcity of local surface as well as subsurface water emphasize this need. A lot of people still don't have access to water due to an inadequate use of it so that there is a stringent need to find urgent solutions to such a concern.

Although many efforts have been made through several actions the problem remains unsolved.

Developing countries and arid countries have pursued the goalof a correct use of water due for its scarcity. However, also in not

arid countries, traditional interactions of man with natural ecosystems started with agricultural activities and followed a higher respect of natural conditions as well as resources.
The increased demand for water and availability of new technologies and energetic inputs, deeply changed the way of using natural resources; where surface water is not available, modern pumping technologies providing access to previously unknown or inaccessible groundwater reservoirs are coming into a widespread use. Population and governments are induced to abandon traditional water supply systems in favour of modern hydraulic systems characterized by a higher productivity enabling to satisfy new necessities, however, in many cases, overcoming the carrying capacity of different systems.

The provisions of UNCCD recognize traditional knowledge a pivotal role as being a part of a range of technologies and techniques which could be harnessed to manage arid ecosystem in a more sustainable way. The benefits of such a traditional knowledge are connected to the identification of useful farm practices (poverty reduction), plant and animal species (conservation and diversity), and forms of social organisation which are well suited to particular farming systems (community empowerment). To fully utilise these benefits, mutual reciprocity between traditional knowledge and modern technologies has to be promoted through an integrated approach.

A very interesting example of traditional knowledge in water management is represented by the complex system of horizontal wells or underground infiltration galleries spread in South-west Asia, Northern Africa and in Southern Europe (essentially Spain and Italy) and South America.
Centuries ago, across much of the Arabian Peninsula, thousands of subsurface water channels were excavated into alluvium and bedrock, bringing water from mountain aquifers to arid and semi-arid valleys and plains. These underground canals are known as qanats (Arabic: canal), but have been called up with different terms around the regions they had been found.

In Iran, Afghanistan, and Pakistan they are karez. This is also the name that those who travelled to the North-western China via the old Silk Road preferred. They are ialaj in Oman, ghayl or miyan in Yemen, qanat Rornani in Syria, foggara in Egypt, Libya and Algeria, and khettara in Morocco. In Spain, where the Islamic Umayyad empire was responsible for introducing this technology, they are mayrit or galeria, and they are called galeria or puquio in Mexico, Peru and Chile, where they were introduced by Spanish colonists (Lightfoot, 2000).

2. General description and short history

An important description of these traditional water supply techniques can be found in the work of Cressey, published by the American Geographical Society in 1958, which also provides a very interesting description of the construction methods as well as costs. These have also been taken into account in the work by E. Noel (I944), P. H. T. Beckett (I953). Qanats are described as "*gently sloping tunnel, often along the radius of an alluvial fan, which extends upslope until the water table is tapped and emerges at the downslope end to supply an oasis or agricultural fields*" (Cressey, 1958).

The length of a qanat ranges from a few hundred yards to tens miles and the upper end may be several hundred feet below the surface. The upper part of the tunnel, below the water table, serves as an infiltration gallery and may have several branches to increase the inflow. The lower and longer part is the conveyer channel. The section between the two shafts is known as a "ptishteh". Seepage losses may be high, even as much as one-third but in some cases the accumulated clay tends to waterproof the channel. The yield of water varies widely from qanat to qanat and from season to season, but it is usually several cubic feet per second. By this means, thousands of acres are irrigated and hundreds of villages receive their sole water supply.

Qanats first appeared in the mountains of Kurdistan in Western Iran, Eastern Turkey and Northern Iraq more than 2.500 years ago together with early mining in that region. Several factors explain this origin. Most importantly, perhaps, this region is one of the oldest mining and metallurgical centres in the MiddleEast.

The need to dig tunnels in order to search minerals meant that the inhabitants of that region had mastered the basic technology necessary for qanats construction. The City Hall of Persepolis is thought to have been supplied by qanats about 500 B.C. Near the Mediterranean area, qanats are erroneously attributed to Romans. The term karez is Persian but it is used more frequently outside Iran than in the country itself, where preference goes to the Arabic word qanat, meaning a subterranean canal or conduit for water. In Northern Africa the usual term is foggara. There are some two dozen variants of the name or spelling: qanat, quanat, canant, connought, kanat, khanate, khad, kanayet, or ghannat; karez, kariz, kahriz, kahrez, karaz, or kakoriz (Southwest Asia); foggara, mayon, iffeli, ngoula, khettara, khottara, or rhettara (North Africa); falaj, aflaj, or felledj (Arabia) (Cressey, 1958). Most of these gravity-flow drainage galleries are quite short (few kilometres (Beaumont, 1989), but tunnels extending for 40-50 km can also be found (English, 1998).

Fig. 2. Excavation of a qanat in Iran (Photography by Cressey, 1958.)

2.1. Methods of construction

Qanats have always been considered as systems being essential for human being's life in arid regions. For this reason, they have been subjected to specific laws aiming at regulating their construction and use while setting the distances between tunnels and introducing respect areas around them.
The construction of a qanat is quite a dangerous operation requiring specialized skills so that a lot of diggers (called "*muqannis*" in Iran) prefer transferring their knowledge and ability from generation to generation (Fig. 2).
The qanat is built by an initial sinking of a shaft deeply enough to prove the presence and depth of a water-table. When water has been reached, it must be necessary to verify that there exist a sufficient water supply and a suitable height of water table. Afterwards, a line of shafts, spaced at intervals of 20-80 m, must be dug into deep in order to reach the aquifer; the most upslope shaft is called the "mother well" (*madari chah*). Between shafts a gallery must be constructed, generally starting from the lower end, up-slope from the point selected as the outlet of the qanat. The gallery continues below the water-table into the aquifer for some distance: it is at this level that water seeps into the gallery. The shafts let the access to galleries as well as removal of spoil during the digging which are necessary for ventilation (Fig. 3).

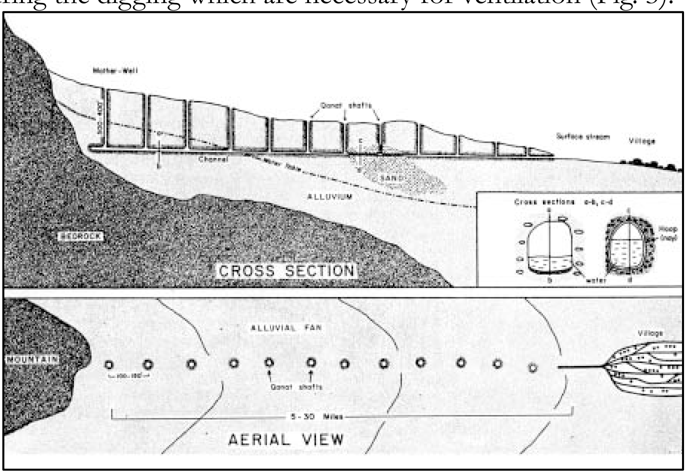

Fig. 3. Scheme of a qanat (English, 1998)

Tunnels and shafts are not necessarily lined, except in areas of weakly consolidated sediments. In such cases, elliptical baked clay rings are used. Depending on the water flow, the excavation may start from the lower end or from the mother well. The slope of the tunnel is a very important characteristic for the correct working of the system: it must be very gentle to avoid water's rushing down and to prevent walls' erosion and the qanat's collapse; at the same time it must not be too shallow to prevent water stagnation in the tunnel. The success of the construction depends on the ability of skilled "muqanni" who, while using very simple tools, are able to calculate the proper alignment and gradient of the qanat which might extends for kilometres (English, 1998).

Around each shaft, a ring of earth is accumulated to prevent the flooding of tunnels with surface runoff after a storm, being a distinctive feature of landscapes in the regions where this technique is used (Fig. 4).

The length of qanats, their maximum depths and their water flow vary widely; however, in any single area, similarities between qanats are usually found (Cressey, 1958, Beaumont, 1968).

3. Diffusion of qanats

3.1 The Arabian peninsula

Many studies have been carried out aiming at describing the diffusion of this technique in the Arabian Peninsula. However, despite the efforts that many scholars have put forward, existing gaps are still present even if research conducted in Syria, Jordan and Yemen, in the period from 1993 to 1998, has contributed to bridge those ones. Surveys by various governmental agencies suggest that the number of qanats in operation is about 25.000.

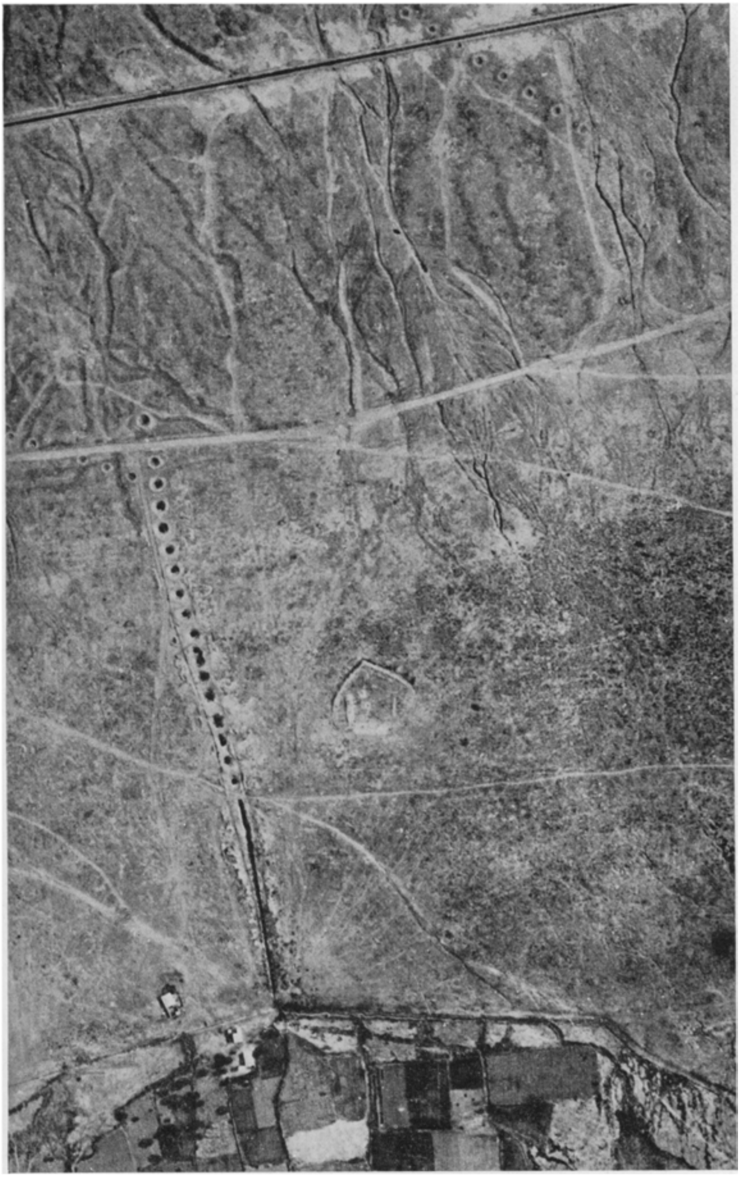

Fig. 4 Aerial photograph of a qanat: the ring of excavated earth around each well shaft is plainly visible from the air

Qanats are widely spread in Iran where this technology was created between the tenth and the eighth centuries B.C. and it is there that evolutionary experimentation has created the greatest varieties in terms of length, depth, and form. These qanats once provided as much as 75 % of the water used in Iran and irrigated about one half of cultivated lands.

Almost all of qanat systems in Iran are found in coincidence with large alluvial fans in the piedmont zone between high mountains and the kavir or salt desert or in large alluvial valleys on the desert margin (Beaumont, 1971).

In Oman, where qanats are most numerous outside Iran, falaj still provided more than 70 per cent of used water and irrigated about 55 % of cropped land as late as the 80s (Lightfoot, 2000).

Although numerous changes in terms of modernisation of irrigation techniques have occurred in several areas of the country and qanats have lost their role in the water supply, in many parts of Iran, the qanat is still the main and only source of irrigation and domestic water-supply.

Indeed, in areas of sparse population or low-yielding aquifers, the relative efficiency of the qanat means that it is unlikely to be ever replaced.

3.2 Syria

A very interesting study dealing with qanats in Syria was carried on from 1993 to 1998: the research project aimed to examine the role of qanats in a modern world. Fieldwork was conducted in winter 1993 and summer 1994 in order to determine the distribution and status of qanats throughout Syria, evaluate the historic role of these qanats, determine why qanats were built in the place where they had been found, why their use had so dramatically declined in recent decades, and what impact these changes have had on Syria's ground-water resources (Lightfoot, 1996).

Qanats have been present in Syria for many centuries providing water for irrigation or drinking use also in some areas without surface water probably since 6-7th B.C. The diversity of qanat

types seems to reflect a great variety of origins. For example, engineering and architectural forms associated with qanat shafts and vent openings are not consistent (e.g. masonry or dirt in shaft and around vent shoulder; variations in diameter and spacing), qanat tunnels vary widely in design (e.g. height and width; oval to rectangular profiles; natural interior or various forms of wood, masonry, brick, or cement casing; continuous gradient *vs.* the floor of the tunnel excavated to create one or more subterranean reservoirs in line with vertical shafts), and the water might sleep into a canal called up as a birka (small reservoir or holding tank for irrigation water), or a large well.(Lightfoot, 1996)
Syrians call all qanats as "Roman canals" or "Qanat Romani"; indeed they were introduced in Syria by the Persians although the majority of Syria's Qantas have been built during the Roman Byzantine era.
Qanats requires a careful management in order to maintain their efficiency; many of them have been abandoned since the 18th century, many others disappeared in the last half of the 20th century as a consequence of water table fall due to the introduction of modern pumping methods.
In the framework of a recent and interesting project aimed at recovering traditional and sustainable methods for water supply, in the summer of 2000, a qanats network in the South-West of Aleppo was cleaned and renovated (Wessels et al, 2002).
Some difficulties arouse from the project arose while recovering ancient qanats, mainly social difficulties (the common management requires a social cohesion of the community or a clear ownership and regulations). At the same time, technical difficulties could be found because the balance and the working of the qanat system strictly depends on the level of groundwater and it is seriously threaten by pumping in areas within a range of 3 - 4 kilometres from the tunnel.

3.3 North Africa - Algerian Sahara

In arid countries of Northern Africa, where rainfall are very low (less than 100 mm/year), or null, the only possibility to survive is represented by the use of non renewable fossil aquifer. In the

hearth of Sahara, thanks to the traditional ancient technique which makes use of underground drainage tunnels, (foggara, as they are called locally), water resources are caught and let the presence of sebkha oases in these hyper-arid regions.
Two types of foggaras can be recognized: one which captures the system of deep water of the Continental Intercaler, called up as "Albian foggara" and the foggara which captures the water of the Occidental Erg Large, denominated as Erg's foggaras (Remini et al., 2010).
The foggaras of the sebkha oases do not go down as far as the water table. However, where possible, they drain off the top part without causing the water table to fall. Just enough water was siphoned off to let the restoration of the water table which is fed from the atmosphere. According to Laureano, there are three types of atmospheric supply. The first is from rainfall over the highlands and faraway mountains which constitutes the slow recharge of the aquifer. The second atmospheric supply to water table comes from a regular precipitation which, in these hyper arid regions, does not exceed 5 to 10 mm per year. It represents an important contribution for the enormous size of the basin. The third source of supply is due to a phenomenon of condensation of the atmospheric water, caused by the huge temperature excursion from day to night and collected into the underground tunnels of the foggaras. Some of the foggara networks which are typical of Touat are fed in this way and are not dug deep underground and are called surface foggaras (Laureano, 1998).

Fig. 5. A well of foggara in Timimoun (photography Remini and Achour, 2008)

Since the 1960s, foggaras are gradually disappearing because of social, economic, technical and environmental problems. The excavation of deep wells and the consequent substitution of traditional methods with modern pumping systems have determined a lowering of water table and the reduction of water flow making the water supply insufficient for the population requirements. It must be noticed that substitutions of shared water management versus single ones also implies a deep change in the social structure of the community. Furthermore, many of

the foggaras are subject to degradation either for the silting of galleries filled with sand during sand storm either for the penetration of a wild plant penetration called "Terza".
At present, the system is really endangered due to a lack of maintenance. The risk is the complete loss not only of a traditional method for water supply, but also of a social system and of a sustainable cultivation of the oasis. Infact, the increased availability of water, following the modern pumping devices pushing towards the intensification of the typical oasis' palmeraie which are loosing their agricultural biodiversity or, towards the complete abandonment of foggaras whose functionality is completely compromised while modern technologies are not available (Monguei, 1974).

4 Italy: the "cunicoli" of Tuscania

Similar systems of tunnels can be found mostly in Southern Italy. The Sassi of Matera in Southern Italy are considered to be the prime example of how archaic societies lived and managed resources throughout the karst areas of Lucania, of Apulia and Sicily and which are still, up to day, unappreciated and unknown.
The case of Matera is very interesting even though it is less known than the case of Tuscania (Latium, central Italy). In this paper the preliminary results of the survey, aimed at understanding how the Etruscan draining tunnels called cunicoli could be compared with other kind of hydraulic water tunnels spread across the countries of the Mediterranean basin, are reported.
The research was conducted with the characteristic approach of the Foggara Project which is paying attention not only to the cultural aspects but also to functional ones. This represents an important innovation, since the most part of the research held in Italy up to today has mainly given priority to the archaeological aspects, while little attention was paid to investigate whether these devices could play a role, today or in the near futurue, as an active resource in water management. The research has, thus,

firstly highlighted the scarcity of sources that are limited in describing how vast the spread of cunicoli is on the former Etruscan region which does not fully depict the complex relations that these have with the ecosystem and the cultural landscape. Secondly, it has outlined how these devices play a major role, still today, in the correct and sustainable management of water and the territory. As regard as the width of the subject, the survey within the Natural Reserve of Tuscania has led to identify some 25 independent hydraulic systems in an area of 19 km^2, be it 1,32 systems per km^2, a density about three times higher than the one of those areas previously studied. As regard as functions of cunicoli, actual sources are able to represent the multiplicity of purposes these were dug for, although most authors, while analyzing mostly and merely small realities, have focused on one of them and have rarely been able to correctly depict the complexity of the subject. By this perspective, comparison with desert oasis was particularly interesting, for it made it easy to understand how different hydraulic devices (i.e. water collecting and draining) are complementary to each other, as well as how strictly related they are with land management and above ground settings. It also led to realize how, even if located in completely different environments, the huge net of cunicoli and foggara are basically working upon the same principles: it appears quite clear, in fact, that even in the case of the cunicoli, long tunnels represent a key for creating an exchange surface with the underground. Through the surface of their tall walls, unlined nor plastered (and therefore permeable to water), they are not only able to collect all kind of underground water - be it *captatio* of the water table, collection of micro fluxes or condensation of atmosphere humidity - but they also give the opportunity, when properly managed, to help water to infiltrate into the underground capacity, to store it and make it available at a later stage.

5. Conclusion

The underground system for water supply (qanat, foggaras, cunicoli) share a common approach: water use and management. By this system water becomes a renewable resource.

The flow of water depends on the level of water tables never exceeding the natural capacity of the aquifer being a sustainable system of water supply.

The great advantage of this system over the well is that groundwater can be continuously obtained without the need to involve human, animal or mechanical power. With respect to other added systems, they are made of local materials. The minimum loss of water through evaporation made this technique very suitable in countries that were characterized by high temperature and solar radiation and region of high risk of desertification.

The systems, though, introduce some disadvantages: the discharge of the qanat is proportional to the difference in hydraulic head between the water-table in the mother well and the water-table in the down-slope end of the water-producing section. This difference is a function of the length of the tunnel into the aquifer beneath the water - table and of the gradient of the water-table itself. Because the qanat penetrates only a few metres below the water-table, small seasonal fluctuations in the water-table level can have considerable effects upon discharge. Furthermore, pumping actions in a small range from the system of tunnels can affect its functionality

The variability in water supply depending on water table level makes this system sustainable from the water resources' point of view. It can result inadequate for the present increased demand for water. For example, this huge variability produces uncertainty in the amount of available water and results in cropping strategies oriented towards the cultivation of crops with lower water requirements which are also low value crops.

Usually the greatest qanat discharge occurs in late winter and early spring and the lowest discharge in late summer and autumn. The fact that the qanat flows throughout the year as well as that

its flow cannot be regulated means that a considerable proportion of water is allowed to run waste in the winter months when irrigation water is not needed (Beaumont, 1968).
The question arising is: "Are modern systems with continuous pumping sustainable and profitable in such areas with very low precipitation and recharge of groundwater?
Although in our country water scarcity is not so evident, the awareness of a necessary sustainable use of water and human activities makes this topic very urgent.
The comparison between the nets of tunnels present in arid countries and the cunicoli found in Tuscania is to highlight the existing difference in terms of methods for producing water: while the desert relies mainly on hidden rains, our environment benefits from a great amount of water available. But they also appear to have many common aspects. They were not only dug by using similar techniques, they not only were both gravity driven (with all the implications on sustainability that this implies) but above all in both cases the sum of small, multipurpose devices proves to be an artificial modification of the ecosystem, able to improve human life standards. This is an an intervention that, based solely on natural dynamics, has proved to be effective and sustainable in the last decades. The research, at the end, made it possible to understand scarcity of sources and the emergency of proceeding with the study of a subject related not just to the environment but also to cultural heritage and landscape as well as land management.
This is an issue that evokes, from one side, the debate on protection and the use of cultural heritage; and from the other one, it makes the paradox of modern farming, a primary activity having to depend on subsidies, so much evident.
The author, in conclusion, highlights how the cunicoli represent an extraordinary solution whose protection relies on the delicate balance of the whole ecosystem and whose importance shall not be forgotten while approaching the difficult questions raised by the crisis of the Italian farming as well as the climatic changes that are on sight.

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