Bridging Mediterranean cultures in the International Year of Soils 2015: a documentary exhibition on irrigation techniques in water scarcity conditions

S. Barontini, V. Boselli, A. Louki, Z. Ben Slima, F. E. Ghaouch, R. Labaran, G. Raffelli, M. Peli, A. M. Al Ani, N. Vitale, M. Borroni, N. Martello, B. Bettoni, A. Negm, G. Grossi, M. Tomirotti, R. Ranzi and B. Bacchi

ABSTRACT

The paper presents the activity performed at the University of Brescia by students and researchers, belonging to different Mediterranean cultures and different disciplines, to prepare a documentary exhibition on irrigation techniques in water scarcity conditions, on the occasion of the International Year of Soils 2015. Traditional irrigation techniques were identified as a key aspect of soil conservation and agricultural practices, to build living and autopoietic ecosystems, also in adverse climatic conditions, and to adapt to climatic changes. Being a structural source of ecosystem survival, and being based on long-lasting observation of the climate and of the environment, they have deep roots in local cultures and they were identified as a common ground also for multicultural interaction. The core of the exhibition is structured in sections focused on techniques for collecting groundwater, atmospheric humidity and surface water, on water lifting techniques and on water distributive systems. The final section of the exhibition is devoted to the oases which are presented as an equilibrium ecosystem, established upon the alliance between man and nature and founded on the capability of collecting water.

Key words | cultural interaction, International Year of Soils 2015, resilience and adaptation, traditional irrigation techniques, transition ecosystems, water scarcity

S. Barontini (corresponding author)
V. Boselli
A. Louki
Z. Ben Slima
F. E. Ghaouch
R. Labaran
G. Raffelli
M. Peli
A. M. Al Ani
G. Grossi
M. Tomirotti
R. Ranzi
B. Bacchi
Università di Brescia, DICATAM,
Via Branze, 43,
I-25123 Brescia, Italy
E-mail: *stefano.barontini@unibs.it*

N. Vitale
Slow Food Lombardia,
Via Rismondo, 10 (private address),
I-25128 Brescia, Italy

M. Borroni
Università Ca' Foscari,
Dorsoduro 3246,
I-30123 Venezia, Italy

N. Martello
Fondazione Guido Piccini per i diritti dell'uomo ONLUS, Via Terzago, 11,
I-25080 Calvagese della Riviera (Brescia), Italy

B. Bettoni
Università di Brescia, DEM,
Via San Faustino, 74/b,
I-25121 Brescia, Italy

A. Negm
Università di Palermo, DiSAF,
Viale delle Scienze 12, Ed. 4,
I-90128 Palermo, Italy

INTRODUCTION

During the 17th World Congress of Soil Science, held in Bangkok in 2002, the International Union of Soil Sciences (IUSS) took a resolution in which worldwide organizations were addressed to install an annual day of the soil, preferably on December 5th (IUSS 2002), to celebrate the soil as a crucial component of natural systems and human wellbeing. Later, in June 2013, the FAO Conference endorsed World Soil Day (WSD) and proposed the official adoption at the 68th UN General Assembly (FAO 2016a). Finally, on December 20th, 2013, the 68th UN General Assembly recognized the date of December 5th as WSD and declared the year 2015 as the International Year of

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Soils (IYS), with the purpose of raising awareness worldwide of the importance of soils for food security, agriculture, mitigation of climate change, poverty alleviation, and sustainable development; and they recognized the 'urgent need at all levels to raise awareness and to promote sustainability of the limited soil resources using the best available scientific information and building on all dimensions of sustainable development' (UN 2013). During the celebration of the IYS, on December 7th, 2015, assessing the achievements and the future challenges of the IYS, the IUSS together with the Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture drafted the Vienna Soil Declaration 'Soil matters for humans and ecosystems' and the decade 2015–2024 was proclaimed the International Decade of Soils (its end being the centennial IUSS anniversary; IUSS 2015).

Water availability and management are structural for agricultural purposes and therefore for food security. At the same time, they are key aspects of most soil conservation issues. Referring in fact to the classification proposed by the Soil Thematic Strategy published by the European Commission (2012), water plays crucial roles at least in four of eight main soil degradation processes (erosion, salinization, landslide, and contamination) and the water cycle is strongly affected by three others (decline of soil organic matter, compaction, and sealing), whereas desertification is regarded as a cross-cutting issue induced by other degradation processes, namely, erosion, organic matter decline, and salinization. It should be pointed out that desertification does not necessarily spread from a desert and arid region, but is a 'slowly creeping phenomenon' (Şen 2008) which can take place in any area, starting from localized spots, even far from arid conditions, and essentially due to land degradation.

A cultivated land is an anthropized environment in which natural resources and anthropogenic activities symbiotically act to guarantee the food production and ultimately the food security. According to the interpretative framework proposed by Laureano (1995 (2013)), after investigations in the Sahara region, in the Arabic Peninsula, in the Middle East and in Southern Italy, the symbiotic relationships become structural in areas in which, due to the adverse climatic or soil conditions, only the alliance between man and nature allows the building of living and autopoietic ecosystems. An important case, proposed by the author as the key to understand these relationships, is that of the oasis. Thanks in fact to this equilibrium between natural resources and anthropogenic activity, oases are settled and survive in arid areas, in most of which the original organic activity of the soil is practically absent and the preliminary steps of soil development are inhibited by wind erosion. In these environments, starting from the Iron Age (third millennium BP), people slowly developed effective techniques to slow runoff (e.g., the terraces in the Negev and Sinai), to store monsoon precipitations (the barrages across the wadis in Yemen) and to collect groundwater (even if far from the area chosen to become an oasis, as e.g., the qanats in the Persian Plateau), which allowed cultivation of arid and mountain regions (Liverani 1996).

The symbiosis and the alliance between man and nature leads to a coevolution of environment and society, so that any change has fallout on both the environmental and social systems (Laureano 1995 (2013)). The structural role of the coevolution of water management systems and social systems was stressed also by Montanari et al. (2013) in the framework of the Panta Rei decade (2013–2022). Climatic changes, climatic seasonality, and social changes induce, in natural and anthropized systems, states of transition (e.g., Rotmans et al. 2001), which often become states of continuous transition, due both to the long time evolution of the external changes and to the long time required by the system to fully react to the changes and to move to a new dynamic state of equilibrium. From an agricultural point of view, a major source of crisis can be the change of water availability, particularly in the case of a decrease in availability. In these scenarios it seems that traditional farming systems, based on small farms with great biodiversity and selected drought-tolerant local varieties, are intrinsically resilient and prove to have a large potential to adapt to climatic changes (Altieri 2009; Altieri & Nicholls 2013).

Taking inspiration from all this information, we identified the traditional irrigation techniques as a key instrument for soil conservation in arid and semiarid areas. Then, in early 2014, we started designing and building a documentary exhibition to introduce to a large audience the similarity between these irrigation techniques in arid and semiarid areas around the Mediterranean Sea. The exhibition was aimed at being displayed for students, both in secondary schools and universities, and in public circumstances, as e.g., local celebrations or congresses. Until now it has been displayed about ten times and presented in a public lecture given at the Museum of Natural Sciences of Brescia. The project was developed in a multicultural and multidisciplinary framework with the contribution of students, researchers, and independent scholars. On the one hand, the traditional irrigation techniques provided a common ground of investigation and a means for cultural interaction between students linked to both the local community and to the Arabo-Islamic ones. On the other hand, researchers and independent scholars belonging to many disciplines, namely, architects, historians, hydrologists, and philologists, contributed to the project. In the documentary exhibition, which is now available as a technical report of the University of Brescia (Barontini *et al.* 2016), we concentrated on six main topics: the first three concern water collection, respectively from the groundwater table (qanats), from the atmospheric humidity (cob walls and dry stone walls), and from the surface water (wadis, barrages, and cisterns); the fourth and the fifth topics concern water lifting technologies and distribution in agricultural fields; the sixth one describes some aspects of the oases, as based on the previously introduced techniques.

In this work, after briefly introducing the case of Brescia and its social changes, which underlie the stimulus to the work, we present the concepts behind the exposition and finally the exposition and its structure.

POPULATION DYNAMICS AND INTERACTIONS: THE CASE OF BRESCIA

Brescia and its province are experiencing a dramatic change in their social and economic structure: in recent years, Brescia has been chosen to be their residence and work place by many foreigners, coming from all over the world, and it has become one of the cities in Italy with the greatest percentage of migrants.

The percentage of resident migrants in the province of Brescia was around 6.8% in 2004 and it grew to 13.2% in 2015 (ISTAT 2015). It is greater than both the national average (8.2% in 2014; Comuni Italiani 2016) and the regional one (11.5% in 2014; Comuni Italiani 2016), and it is comparable with that of the province of Milan (13.7% in 2014; Comuni Italiani 2016). Nowadays, the province of Brescia has a population of about 1,260,000 people, 167,000 of whom are regular migrants. Among these, about 16% (26,700) come from the Middle East and North Africa (ISTAT 2015). Migrants are not uniformly distributed throughout the province's territory, and are more present in the city of Brescia (19% in the city versus 13.6% in the province in 2011; Chamber of Commerce 2011) comparable to the neighboring province of Milan (18.6% in the city versus 13.7% in the province in 2014; Comuni Italiani 2016).

This change is an important challenge for the city, both from the social, cultural, and economic point of view. Focusing on the cultural aspect, the interaction between cultures is an opportunity for reciprocal enrichment, which, at the same time, requires a deepening of the knowledge and the understanding of both the local and the migrant backgrounds. It is recognized that this process, which requires going back to and reanalyzing the roots of each identity, has positive fallout also on the social aspects, as it contributes particularly to second- and third-generation migrants not to feel rootless. In this context, students from the University of Brescia, both linked with the local and with the Arabo-Islamic communities, constituted a study group named 'Al-Bīrūnī', with the objective of cooperating with local students and researchers to investigate and to promote cultural initiatives to explore the differences and the interaction between Arabo-Islamic and European cultures. The name is meant as a tribute to the Persian scientist Abū Rayḥān al-Bīrūnī (about AD 973–1051), who was an engineer, scientist, geographer, astronomer, and historian of the Islamic East. The importance and, to some extent, the exceptionality of al-Bīrūnī lies in the great variety of his production, which covers topics as diverse as pharmacology, astronomy, anthropology, together with engineering and history. He always proceeded according to a method that can be best described in al-Bīrūnī's own words: 'Reliance on personal observation and on-the-spot examination enhance the capacity to remember and distinguish the facts and also to identify objects, not only in pharmacy, but in other professions and crafts. Gathering data through direct handling and observation is a greater advantage to be encouraged over mere reading of books' (Gafurov 1974). Even though al-Bīrūnī's empiricist approach had a lesser impact on the history of science in the Muslim world, than Galileo's had on European culture, by choosing the name of 'Al-Bīrūnī' for the study group, the students intended to envisage a sort of intriguing parallelism between the two scientists.

CONCEPTS

The exhibition focused on traditional irrigation techniques in countries surrounding the Mediterranean Sea, because they provide a common cultural background between the different origins of the participants and they are structurally linked with key aspects both of sustainability of the agricultural production and of cultural interaction. In particular these aspects are: (1) mitigation of the fallout of climatic and anthropogenic changes on agricultural systems; (2) management of water scarcity conditions; (3) adaptive capability to changes; and (4) cultural transfer due to travelers and skilled workers' migration. Starting from these concepts the exhibition aimed at disseminating two main ideas: (1) a dense network of cultural and economic relationships, around the Mediterranean Sea, leading to technological similarity of the main water supply systems in countries affected by similar conditions of water availability; and (2) in environments characterized by severely or extremely adverse climatic conditions, an agricultural system can survive only in equilibrium with the surrounding nature. In the following sections the main concepts previously introduced will be briefly detailed.

Climatic and anthropogenic changes

According to the Fifth IPCC Assessment Report, there is a general consensus about an increase of the global average temperature in the current century (IPCC 2013), even if the magnitude of the warming greatly depends on the scenario of greenhouse gas emissions (FAO 2016b). Temperature increase has the direct effect of exposing the soil to degradation, by means of drawbacks on the main soil processes, namely, organic matter decomposition, leaching, and soil water regimes (WMO 2005). At the same time, an increase in temperature will trigger an increased water demand for evapotranspiration (FAO 2013), which will conflict with the precipitation decrease projected by climate models for the Mediterranean and Southern Africa (FAO 2016b), thus increasing the climate pressure on the soil. Climatic changes are observed to have negative impacts on food production in most cases (Porter *et al.* 2014) and, in many areas, they are accompanied by human and social changes. Due to population growth, these lead to an increase of agricultural and sanitary water demand and induce a reduction of the soil capacity of storing water as a consequence of urbanization and bad soil management policies (e.g., Fischlin *et al.* 2007).

Water scarcity versus water aridity

In this framework, and to focus on the links between farming and the environment with a sustainability perspective, we chose to stress the concept of water scarcity conditions, rather than that of aridity or drought conditions. Scarcity is an equilibrium concept related to the balance between (water) availability and need (Falkenmark *et al.* 1989), while aridity and drought are more strongly climate-related concepts, dealing with more or less permanent, or occasional water lack, respectively (Maliva & Missimer 2012). Although aridity often implies water scarcity conditions, scarcity affected regions do not generally coincide with arid ones, or with regions where occasionally droughts occur. A meaningful example is that of mountain ranges. Due to steep slopes, thin soil, and difficulties of storing water, mountain regions can, in fact, be in scarcity conditions even in a humid and temperate climate.

Falkenmark *et al.* (1989), dealing with microscale approaches to face macroscale water scarcity and aspects of vulnerability in semiarid climates, classified four water-scarcity typologies, according to four main drivers, which in real cases are typically superimposed. Two of them are of natural origin (i.e., arid climate and intermittent drought years), and the other two are man-induced (i.e., land degradation and population-driven water stress). It is here remarked that population-driven water stress is related to a number of aspects which go from increasing water demand, to minimal irrigation efficiency, to water resources pollution. Madulu (2003) and Anand (2004) highlighted as a fifth typology of water scarcity that related to an economic origin, as the lack of investment in water infrastructures or the fallout of conflicts.

Adaptive capability to changes

The capacity for a territorial system to absorb stresses and to remain functional while facing climatic- or anthropogenic-driven stresses is typically referred to as resiliency.

It is a systemic characteristic which involves all dimensions of social living, both cultural ones and technological and economic ones. Traditional irrigation techniques provide a great contribution to the intrinsic resiliency of traditional farming. According to Laureano (1995 (2013)), who particularly refers to the Mediterranean basin, to the Sahara region and to the Arabic Peninsula, three principal interpretative keys allow this concept to be enlightened: (1) the systems are autopoietic and water collection is in equilibrium with the water availability, thus not impoverishing the available resources; (2) irrigation efficiency is greater, with respect to other conventional irrigation techniques practiced in conditions of water abundance; and (3) the adaptivity of traditional farming is, to some extent, contributed to by the concurrent use of principal and ancillary water collection techniques (see details in the next section). Furthermore, they are structurally linked to the roots and to the culture of local communities, thus contributing to the local cultural identity. Finally, the long-term observation of the climate and of the environment, which underlies both the traditional culture and the irrigation techniques, builds a meaningful capacity of risk mitigation based on reconnaissance of the hazards.

Cultural transfer and skilled workers' migration

The cultural aspect of these techniques provides a fascinating glimpse into the complexity of the nets of cultural interaction. Most of these techniques are very ancient, the first terraces and barrages belonging to the Iron Age (third millennium BP; Liverani 1996). Afterwards they were diffused along the trade routes by travelers, skilled workers, and treatises. Take, for example, the case of qanats, which originated on the Persian Plateau during the Preachemenid Age, spread throughout many areas of the Middle East and Far East, reaching Chinese Turkestan along the Silk Road, and, with the diffusion of the Arabo-Islamic culture in Northern Africa, reached the central Sahara region, Spain, Cyprus, and Sicily (Tölle-Kastenbein 1990 (1993); Ahmadi *et al.* 2010). Then, in Spain, the Arabo-Ispanic culture interpolated the Greek-Roman one and allowed the development of Spanish agricultural civilization, which in the Medieval Age reached its greatest development and influenced European agriculture in the early modern age (Ciriacono 1994).

THE EXHIBITION AND ITS STRUCTURE

The exhibition consists of 20 posters (width 70 cm, height 100 cm) conceived with a modular structure to communicate to a wide public the different techniques classified by their purpose and their hydraulic functioning principle. The presentation of the techniques comes after an introduction which provides the keys to read the posters and it is followed by a closure chapter about the oases. The techniques were classified into ones designed to collect, to lift, and to distribute water. The exhibition is then structured into seven sections: (1) Introduction (2 posters); (2) Systems based on the groundwater (qanat, foggara, khettara; 2 posters); (3) Systems based on the air humidity (cob walls, dry-stone walls; 3 posters); (4) Systems based on the surface water (wadis, barrages, cisterns; 6 posters); (5) Water lifting techniques (3 posters); (6) Water distributing systems (1 poster); and (7) Oases (3 posters). In Figure 1 we present a map of the Mediterranean basin and of the surrounding areas with the location of the sites presented in the exhibition. The cases are classified according to the reference chapter of the exhibition. The map is not exhaustive with regard to the huge occurrence and variability of traditional irrigation techniques in scarcity conditions in the Mediterranean basin, but provides an idea of their spread.

For each module are presented the hydraulic concept, key aspects of the traditional building techniques, some historical examples with the corresponding Walter and Lieth climate diagram and with their geographical position in the Mediterranean basin. The systematic approach is intended to let the audience both read the posters straightforwardly and compare the cases. In Figure 2, as an example of the exhibition, a poster about khettaras and qanats is shown.

The climatic diagram is particularly presented with this aim. It gives a first-sight impression of the local climatology in comparison with that of the city of Brescia, which is commonly experienced by the audience, and is presented in the introduction to the exhibition as a term of comparison. This choice allows the public to perceive the deep differences between the climate of a temperate wet area, as the city of Brescia is, and the ones of arid or semiarid areas. As an example, in Figure 3, the climatic diagrams of Palermo (Italy, semiarid climate) and Kébili (Tunisia, arid climate), where the qanat technique is practiced, are reported together with that of

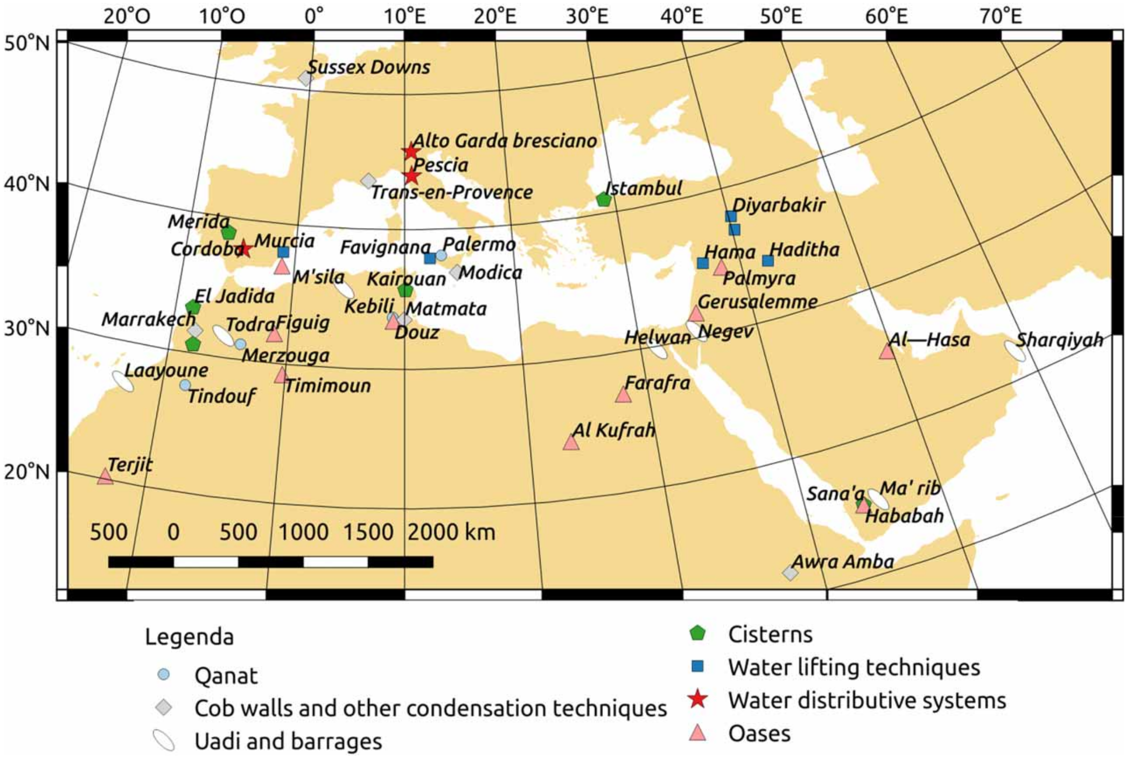

Figure 1 | Map of the cases of traditional irrigation techniques presented in the exhibition (the map was obtained with an Albers equal-area conic projection with standard parallels at 20°N and 40°N).

Brescia. By this comparison, the audience is led to perceive the different issues for water management that can arise when scarcity conditions may occur throughout the year (Kébili), during some months only (Palermo), or can be a priori expected not to happen at all (Brescia). In the following some details on the presented techniques are given.

Qanat

A qanat is a draining gallery which, starting from a groundwater table on the mountains, allows the water to flow downstream by gravity until it reaches the soil surface in the plain (Figure 4). The end of the qanat is always located in a village or in an oasis, with a stilling basin and the divisors to distribute the water to the irrigated gardens. According to some historians, qanats were conceived in the Persian Plateau during the Preachemenid Age, introduced in Maghreb by Arab conquests, and spread along the Silk Road as far as Chinese Turkestan. They are, therefore, an emblematic example of a technological solution to mitigate water scarcity issues, spread over a great area by a complex network of relationships, and subsequently adapted to the local terrain morphology and geology. The qanats are termed in different ways across the world: *kāriz* in some parts of Afghanistan, *qanāt* (pl. *qanāthā*) in Iran (at least in official language), *fouggara* (pl. *fegāgīr*) in Algeria, *falaj* (*aflāj*) in Oman, *ġayl* (pl. *ġuyūl* or *aġyāl*) in Yemen, *kārēz* in Western China, *qanāt* (pl. *qanāwāt*) in Syria, and *khettara* in Morocco. The terminology is actually quite fluid in the many languages involved. More details about the subject can be found in de Planho (2012).

A qanat is carved in the rock, starting from downstream up to intercept the inspection well previously dug upstream where the experts, *muqannīs*, detected a water table. The *muqannīs* were able to track down seasonal streams and, according to the geomorphology of the area and to the flora, to find places where the water table was several meters underground. The best area to start digging the inspection well (called *mother well*) was chosen according to their experience. The underground gallery is connected to the surface by regularly spaced ventilation air wells, needed for excavation, which behave as condensers for the

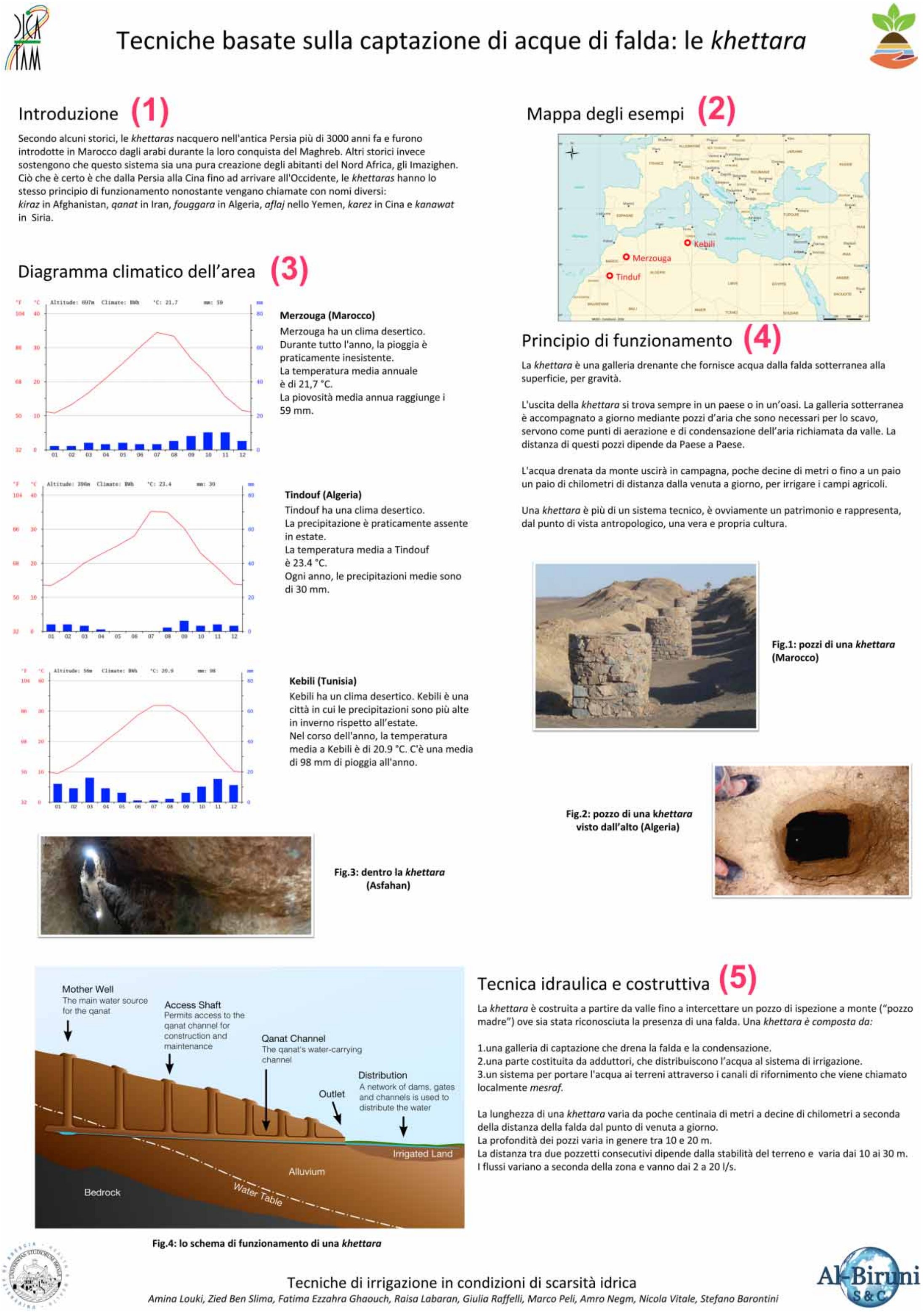

Figure 2 | Example of a poster about khettaras and qanats. The numbers explain the parts of the poster: (1) Introduction, (2) Map of the reported cases, (3) Climatic diagrams of the areas, (4) Functioning principle, (5) Building technique.

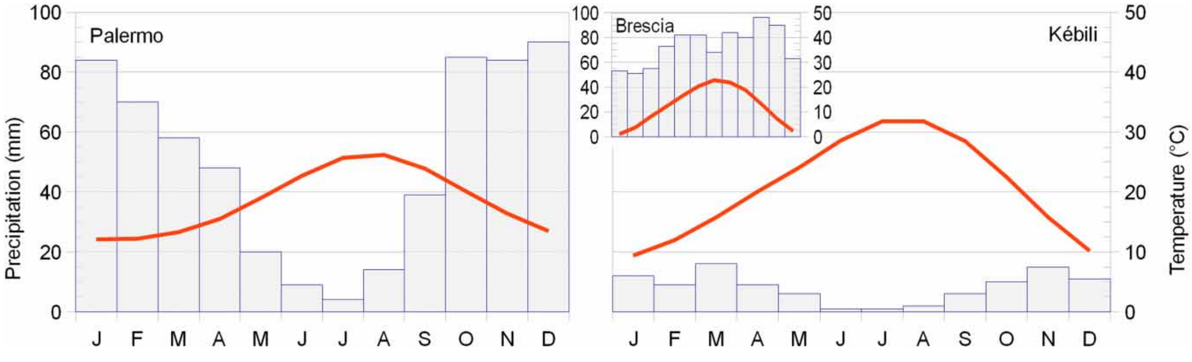

Figure 3 | Climate diagrams of Palermo (Italy, semiarid) and Kébili (Tunisia, arid) compared with the climate diagram of Brescia (Italy, wet). Source of data: http://en.climate-data.org/ (accessed 11 August 2016).

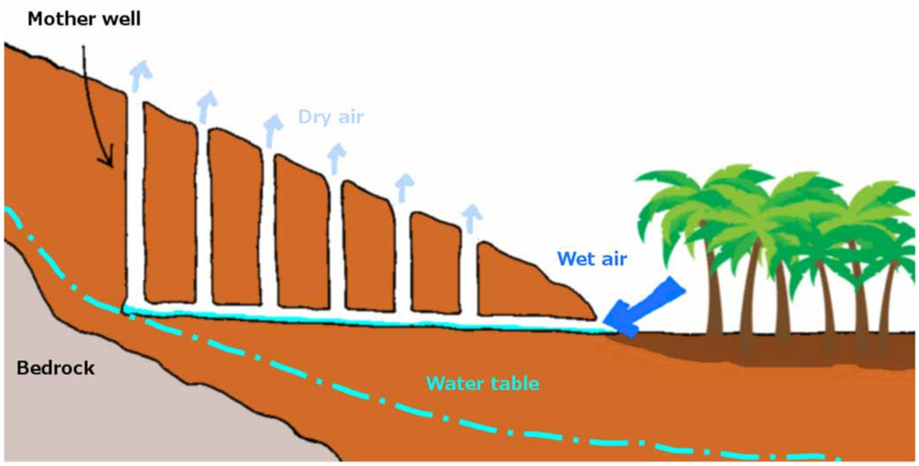

Figure 4 | Sketch of a qanat.

uplifting wet air coming from downstream. The aeration wells can reach a depth of 20 meters, and the distance between two wells depends on terrain stability and is of the order of magnitude of some tens of meters. The discharge drained by a qanat can vary from 2 up to 20 L/s, depending on the surrounding conditions.

Due to its ancient development and widespread diffusion, a qanat is much more than a simple water drainage technology, it is also a structure of precious cultural and anthropological heritage. As an example, in Iran, the International Center on Qanāts and Historic Hydraulic Structures (ICQHHS) is an institution recognized in 2005 by UNESCO with the mission to promote research and development to restore the qanats and other traditional historic hydraulic structures. Qanats are still used in many areas, providing an important part of the water needed for agricultural and drinking purposes, even though in some places they were either recently or historically abandoned. As an example, Lightfoot (1996) depicts a map of the usage of Syrian qanats in 1994, evidencing an increasing abandonment rate after the introduction of motor-pumped wells.

A system of qanats, which is reported as a case in the exhibition, was built in Palermo during the Arab domination in Sicily (AD 827–1091), and nowadays 25 of them, located in the hydrological basin of the Palermo Plain, have been identified (Lofrano *et al.* 2014). Today, three of these qanats (Gesuitico Alto, Gesuitico Basso, and Uscibene), built after the Arab domination, can be explored. They are about 1.5 m high and from 0.6 to 0.8 m wide, with a water temperature around 10 °C. Thanks to its low temperature, the water was also used to refresh some traditional structures named *Camere dello Scirocco* (south-east wind rooms). These rooms were fixtures of old mansions, carved in the rock and kept fresh by the qanat water.

Cob walls and tu'rat

Cob walls and *tu'rat* technique were developed on agricultural land to irrigate by means of condensation of the air humidity or of the collection of little drops of fog. Tu'rats are dry stone walls, often shaped as a half moon. This technique allows the creation of conditions suitable for cultivation at the foot of a wall, where the soil is typically shaped as a cone turned upside down to help water and soil-water content to be collected at the bottom. Condensation happens both due to local energy losses related to the complexity of the geometry, as in the case of cob bricks with a trapezoidal section and in dry stone walls, and to the difference of temperature between warm air and cold wall. This structure is very important for many cases of arid and semiarid agriculture as, even if it is not the main water supply technique, it is in most cases used as an ancillary technique. As a secondary effect, the walls also protect the soil from erosion. Examples of this technique, with different shapes of walls, are found all around the Mediterranean basin. Figure 5 shows an example of a citrus garden at Pozzallo (Sicily): in this case the dry stone walls are high enough to reach the foliage, thus inhibiting the bare soil evaporation. Condensation is traditionally not obtained only by means of cob walls and tu'rats, but also by means of a great variety of both ancient structures and modern prototypes. To give an idea of these, we present the Sussex Downs dew-ponds, which traditionally date back to the Neolithic Age (Martin 1909), the air condenser designed by Knapen in 1930 and built at Trans-en-Provence and a prototype of a water collection tower, the w*arka water,* recently designed by Vittori and coworkers (Warka Water 2015). The warka water is a tissue structure, held by a wooden frame, built to collect water available in fog. The tower is intended to mimic the behavior of the fogstand beetle (*Stenocara gracilis*), which is able to survive in the Namib Desert by collecting fog water on its bumpy back surface.

Wadis, barrages, and cisterns

Wādī (pl. *widiān*, eng. *wadi*) is an Arabic word meaning at the same time valley and water stream. It is used to indicate mountain streams in arid environments. In desert areas,

Figure 5 | Citrus garden surrounded by a dry stone wall at Pozzallo (Modica, Sicily, Italy).

wadis mostly appear as dry torrent beds where water flows on the surface only during exceptional rainfall events, even if sometimes an hyporeic flow is present below the wadi bed and can seldom emerge in depressed areas. The emergence of a hyporeic stream can nourish the vegetation which can be present at the bottom of valleys even in deserts. The Italian geologist Gian Battista Brocchi (1772–1826) was among the first to notice, during his travels in Egypt and Nubia, that the morphology of wadis indicated a recent geological epoch rich with water and precipitations which modeled the canyons. Starting from the Iron Age, barrages were built in Yemen to let, during the rare precipitations, the water level rise in wadis and the water be stored in reservoirs for irrigation purposes (Liverani 1996). During the time of the Roman Empire, there was a great impetus to build barrages in many semiarid areas, both for irrigation and water supply and for soil protection (Tölle-Kastenbein 1990 (1993)). As reported in Figure 1, wadis and barrages are common in many arid and semiarid areas around the Mediterranean Sea, where also southern Italian *fiumare* have a similar hydrological behavior to that of wadis. Through the ages many barrages lost their original purpose and were reinforced and made higher until they became dams, as in the case of the Ma'rib Dam (Yemen), presented in the exhibition.

Another important structure closely related to the collection of surface water are cisterns. They can be both uncovered reservoirs, as in the gardens of Agdal and Ménara (Morocco), or covered ones, with positive effects on the reduction of evaporation, such as the Justinian reservoir of Constantinople (Istanbul, Turkey, 6th century CE) and the Portuguese cistern of el-Jadida (Morocco, 16th century CE).

Water lifting techniques

Water lifting is a common problem, already faced in ancient times and which induced populations to develop a great number of different technologies adapted to local contexts. In the exposition we present the *shādūf*, the *cochlea*, the *sāqiya*, the *noria* and some of the water lifting machines designed by al-Jazari (1136–1206), an important mathematician and engineer who served as chief engineer in the Diyar Bakir region. The shādūf consists of a lever with asymmetric arms with a weight at the short end and a bucket or a skin bag linked by a jointed perch at the long end. A single man operating a shādūf can lift from 2 to 5 cubic meters of water per day considering a difference in level from 3 to 4 meters. The cochlea (7th century BC) is better known as Archimede's screw, from the name of the famous mathematician to whom the invention was attributed in the 3rd century BC. According to more recent investigations (Dalley 2003), the cochlea appears described in a cuneiform inscription of the same epoch of the reign of the Assyrian king Sennacherib (704–681 BC). The sāqiya (5th century BC) is a device consisting of an articulated chain of buckets to lift water (typically to lift underground water) and by gears to transfer the motion induced by a man or by an animal. This technology was probably developed independently in different regions and is widespread in all the Mediterranean area, in India and in China. In Sicily it is known by the local name of *senia* (Barbera 2007). The noria (3rd century BC) is a device composed of a big undershot water wheel with a series of buckets fixed at its lateral side. This technology allows water to be lifted between meaningfully different heights (even more than 20 meters). A big noria can lift up to 300 cubic meters per hour. Norias are important for facing the lack of terrain slope in the Arabic Peninsula and are spread along the Euphrates in Syria and in Iraq. Finally, the water lifting machines designed by al-Jazari were presented to stress the importance of the treatises and literature to diffuse the knowledge about technical innovations.

Water distribution systems

Water distribution in irrigated gardens in water scarcity conditions is traditionally achieved by driving the water at the basis of each tree. As an example, we proposed the case of the citrus orchards' distributive systems around Lake Garda (Alto Garda Bresciano, Italy, Figure 6). Due to the great amount of water required by lemon trees (between 100 and 300 liters per tree every 8 days during the summer season, according to Tedeschi (2006)), the lemon orchards are, in fact, in water scarcity conditions and here a distributive system was developed, analogous to other ones developed in similar conditions in the Mediterranean basin. The cultivation of citrus fruits is such a very old activity along the steep slopes which shape the northwestern shore of Lake Garda, that Renaissance mythology traced its origin to Hercules bringing the citron from the garden of the Hesperides (Voltolina 1574

(2015)). Thanks to the microclimate, induced by the presence of the lake, the cultivation of citrus trees could occur in the ground, more similar to the Mediterranean tradition than to Central Europe orangeries. These *limonaie*, as is the local name, built on artificial terraces filled with soil from the lake's eastern shore, southeasterly oriented to maximize the morning sunlight, closed with wooden and glass panels during winter, allowed the development of a flourishing citrus production in the modern age, whose exports reached as far as Northern Europe. The distributive system consisted of a stilling basin on the course of a small uphill torrent, a channel to convey water upstream of the citrus garden and a system of flumes with a trapezoidal section along the walls to distribute the water at each tree. There was a spillway for each tree, and it was activated by inducing a backwater effect in the flume by means of a sand-filled bag (Figure 6).

Oases

The last section of the exhibition is devoted to oases. According to Laureano (1995 (2013)), they are presented as the manifestation of the symbiosis between man and the environment, that can be built only when a suitable system to provide the required water is identified. An oasis is therefore rarely a fully natural environment, but it is mostly the result of a patient process driven by a correct application of the techniques of water collection, storage, and distribution and of many other measures in order to maintain the very complex equilibrium which allows cultivation. In the exhibition we presented cases of erg oases, piedmont oases, and floodplain oases, subdivided according to the main water collection technique. Piedmont oases and floodplain oases mainly base water collection on barrages built across wadis or rivers. On the other hand, erg oases are situated in deserts and mainly base water availability on qanats, on the capability of condensing transpired water and of protecting the soil-water content from evaporation. This capability is typically achieved thanks to the upside down conical space between the dunes.

CONCLUSIONS

Traditional irrigation techniques are a key aspect of soil conservation and of agricultural practices in scarcity conditions.

Figure 6 | Ancient distribution system in a lemon garden at Lake Garda (Alto Garda Bresciano, Italy). The spilling water was originally accompanied to the bottom of the tree in order to prevent excavation.

In some cases, they allow cultivation of arid and semiarid lands and contribute to an alliance between man and nature to build living and autopoietic ecosystems also in adverse conditions. The coexistence of principal and ancillary techniques of water supply in the same system contributes to the intrinsic adaptivity of traditional farming to climatic changes. Furthermore, being based on long lasting observations of the climate and of the environment, they have structurally deep roots in local cultures. Starting from this information and from the suggestions of the International Year of Soils 2015, we identified the traditional irrigation techniques, practiced in scarcity conditions in countries surrounding the Mediterranean Sea, as a common ground for cultural interaction within a multidisciplinary and multicultural study group of students and researchers belonging to different Mediterranean cultures. The product of this collaboration was a documentary exhibition which aimed at disseminating two main ideas: (1) a dense network of cultural and economic relationships, around the Mediterranean Sea, leads to technological similarity of the main water supply systems in areas affected by similar conditions of water scarcity; and (2) in environments characterized by severely or extremely adverse climatic conditions, an agricultural system can survive only in equilibrium with the surrounding nature.

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