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Khettaras in the Tafilalet oasis (Morocco): contribution to the promotion of tourism and sustainable development

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Abstract

The khettaras constitute a hydraulic system for mobilising water by gravity from the water table to the surface to irrigate fields in oases. This system, which has been fairly widespread in North Africa, in particular in Algeria (*foggara*) and Morocco (*khettaras*), was introduced several centuries ago in the oases of southeastern Morocco and has continued to operate despite various natural and anthropic constraints. Based on these ingenious and millennial hydraulic systems, successive civilisations living in these environments have been able to establish laws and regulations for the management and mobilisation of natural resources, especially water. Indeed, to get the most out of these systems, users have had to abide by rules (*Al Orf/Azref*) designed to protect, promote, and care for the systems to enhance their sustainability. These hydraulic systems have declined in recent years, notably due to extensive groundwater pumping, climate variability (severe droughts), and the local population's disinterest for this type of development. Therefore, we have unfortunately witnessed the loss of a thousand-year-old local ancestral know-how that had been developed by different succeeding civilisations in the area. Recent initiatives (2008–2011) have been undertaken by the Moroccan government for the restoration and development of some abandoned khettaras in the Tafilalet Oasis so that they could be utilised in the development of an oasis-based cultural tourism and integrated in a tourist circuit known as *Majhoul*. This initiative, still in its infancy, has constituted an alternative and a fairly encouraging development for this national and world heritage.

Keywords: Tafilalet oasis, Interactions society–environment, Integrated water management, Water civilisation

1 Introduction

In Morocco, the southern regions experience an arid to Saharan climate and host several oasis ecosystems. The situation of these oases has been alarming. Indeed, they have been threatened by the significant acceleration of the effects of desertification, which have entailed the degradation, then loss, and finally abandonment, of entire oases, whose social, ecological, and economic role has been key in the region, leading people to say that 'combating the degradation of oases is akin to combating the

poverty of the entire population of southern Morocco' (MATEE/DAT-UNDP 2006). This severe deterioration of oasis heritage has been recent and caused by greatly irrational water resource exploitation and completely unsuitable cultivation practices (El Khoumsi et al. 2017). The local population has been especially concentrated near oases, and the economy there has been based almost entirely on local and traditional agricultural production, which is closely linked to the availability of water resources and their management (Aoubouazza and Rajel 2013; Warner et al. 2013; Beraaouz et al. 2014; Abioui and Lagnaoui 2016; Abioui 2018; Beraaouz et al. 2019; Abioui et al. 2019; Angelakis et al. 2020). The increase in water demands, combined with the decrease in precipitation

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induced by climate change, has placed considerable pressure on groundwater (Hssaisoune et al. 2020).

Since time immemorial, the main concern of farmers in these regions has been to research and invent techniques that provide, despite the very severe conditions, a permanent and as regular as possible supply of drinking and irrigation water throughout the year for agricultural production. These techniques have been quite varied. They have ranged from surface water irrigation whenever significant rainfall has filled the wadis to techniques aimed at using groundwater by digging wells and using the khattara system. The khattaras constitute an ingenious system of water management that reveal the ability of humans to adapt their practices to their environment. These hydraulic systems have declined in recent years, notably due to fierce competition with the motor pump and increasingly unfavourable climatic conditions; therefore, overtime, they have disappeared from the panoply of construction techniques used for this kind of system. Young people, especially, have not attached importance to this type of structure and have thought only of migrating or exercising other activities. The vulnerable state of these systems has been further weakened by the threat of climate change and has called into question their operating models. Thus, the khattaras, which were once the pride of the *People of the Oases* and a testimony of their genius, are today condemned to die if current developments perish. Consequences may entail their eradication from the oasis landscape.

Promoting khattaras with an emphasis on sustainable tourism can lead to the conservation, restoration and regeneration of this ancestral irrigation technique.

The main goals of this paper are the following:

- To provide an inventory of the main khattara networks in the Tafilalet region;
- To determine in which context the khattaras system can be considered a heritage;
- To demonstrate the importance of these exceptional systems for sustainable development in the region;
- To valorise this system and promote this system within the framework of cultural tourism;
- To briefly explain how these khattaras systems could be promoted for the enjoyment of curious visitors and to increase their appreciation of the importance of both the cultural and historic heritage these systems represent;
- To protect and safeguard (preserve) these systems through sustainable tourism (also through the protection of oases),

The methodology used in this paper is based on the following axes:

- Bibliographic synthesis of the khattara system and its history;
- Field inventory of wells in the khattara networks for the purpose of mapping it;
- Survey on the construction techniques used for khattaras;
- Semi-open interviews (without a questionnaire) in the study area with local stakeholders such as local elected officials, water users and associations¹;
- Mapping of the khattara networks for the promotion of this heritage within the framework of sustainable tourism.

The methodology used in this work aims to enhance and promote this heritage in the context of sustainable tourism, which will allow the preservation, conservation and protection of this heritage.

In what follows, we give an overview of the history of the khattara system, the stages in the genesis of khattaras, and an example of the valorisation of khattaras in the Tafilalet region within the framework of cultural tourism (Fig. 1). This region was selected because of the importance of khattaras for the survival of oases, as well as the importance of tourist activities in the local economy of this region. We propose that explanatory panels be installed in these stopovers and that sufficiently illustrated and documented brochures be prepared to promote cultural tourism there and increase public awareness about the importance of this cultural heritage for the survival of oases.

2 Khattaras: an unknown world

2.1 The history of khattaras

From the first century on, the importance of groundwater in some regions of the Sahara has led to the creation of a water collection and supply system, as in certain regions of the ancient Middle East (Mesopotamia). Such a system was meant to cover water needs and combat the aridity of the earth and significant evaporation in the arid Saharan regions. It is the system of 'khattaras'.

English (1968, 1998) thought that the technique of khattaras originated in pre-Achaemenid Persia, in the mountains of Kurdistan in western Iran, eastern Turkey, and northern Iraq 2500 years ago. This technique has played an important role in managing the supply of water throughout Iran for over two millennia in an arguably sustainable manner (Manuel, Lightfoot, and Fattahi 2018). Lightfoot (1996a, 1997) suggested that khattaras

¹ The semi-open interviews focused on the oasis's history and water management in order to determine the rules of collective khattara management (khattara management and water sharing) as well as the impact of motor pumps on the survival of this traditional oasis irrigation system.

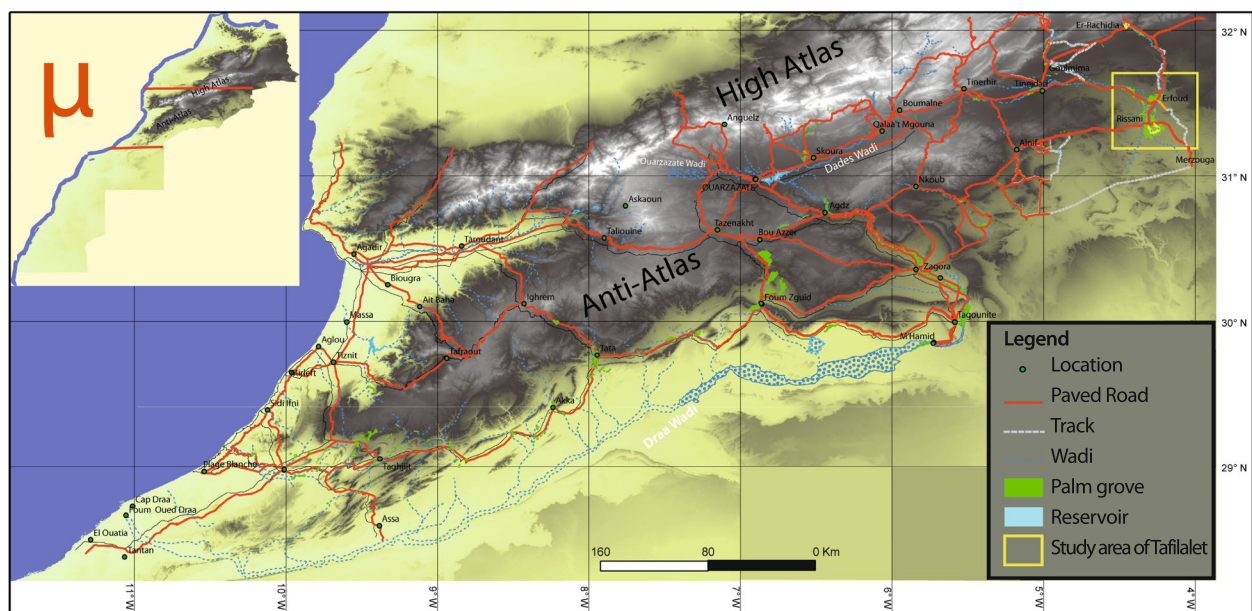


Fig. 1 The study area location map (Source: the authors)

were invented in 600–700 years BC in the Armenian-Persian region. Goblot (1979) mentioned that khetaras were of oriental origin. Cressier (1989) affirmed that the origin of khetaras was undoubtedly located in ancient Iran, and Biswas (1970) (in L'Hote 1990) showed that the khetarra system was born in the eighth century BC in Urartu (near Lake Van, in former Armenia, now Turkey). In general, all these authors have claimed that khetaras originated in an area under Persian influence (Iran or/and the Arabian Peninsula) and that this technique then found its way to the west and south of Europe during Alexander's reign. In Islamic times, the spread of the khetarra technique followed a pattern that closely followed the historical spread of Islam (Smith 1953; Lightfoot 1996b; Violet 2000; Avni 2018). Other authors, such as Hachid (2000), defended that this system is an authentic creation of the inhabitants of North Africa, the *Imazighen*, as evidenced by several historical writings and rock carvings that have subsisted today in the Algerian Sahara.

Several archaeological studies have disputed the notion that the khetaras may have been diffused radially from a single centre of economic and political power to remote peripheries (Magee 2005; Boucharlat 2017). The use of the khetarra might be seen, therefore, as an independent adaptive response to climate change and to the aggravation of water scarcity, which helped ancient communities shift from the use of surface water

to that of groundwater resources (Magee 2005; Labbaf Khaneiki 2019). This technique's general significance may well be that it was a polycentric innovation emerging in different geographical contexts at different periods, especially during the first millennium BC (Magee 2005; Boucharlat 2017).

This technique seems to have been invented independently at least in the Libyan Sahara (in the Al-Fezzan site) (Magee 2005), but this independence in innovation has been more difficult to prove in the case of the khetaras (qanats) that emerged in southeastern Iran and southeastern Arabia. The connection between these two regions in the early first millennium BC has been proven. The introduction and adoption of khetarra technology in southeastern Iran, which had already been perfected in southeastern Arabia, has been suggested (Magee 2005). As a result of the excavations carried out in the United Arab Emirates (UAE) and Oman, Al-Tikriti (2002) stated with confidence that the falaj (khetarra) first appeared in southeast Arabia several centuries before its introduction into Iran.

Today, the construction of new khetaras in the world is very rare or even nonexistent. However, they played an important role until the end of the 20th century in several regions of the world (Afghanistan, Syria, Iran, Morocco, etc.). In Morocco, for example, they have been found in several regions (Tafilalet, Marrakech,

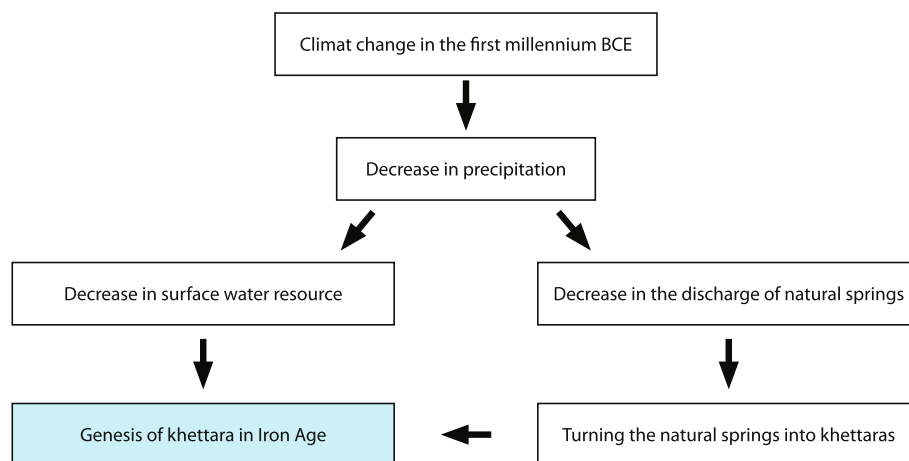


Fig. 2 Relations between the climate and techniques that led to the invention of khattara (qanat) technology throughout the world (Source: Labbaf Khaneiki 2019)

Tata, Fom Zguid, Akka, Skoura, Tazarine, Aoulouz, Taznakht, and Tinghir). The ancestral technique of draining tunnels (or channels) has taken different names in different countries. In Morocco, they have been called khattaras, in Algeria, foggara, in Iran,² qanât, in Egypt and Yemen, aflaj, in China, karez, in Afghanistan, kiraz, in Syria, kanawat, in the Sultanate of Oman, falaj, in Peru, Rio Nazca valley, in France, mines and sublands (in the Ardèche, Drôme, Gard, Hérault, Eastern Pyrénées, and Vaucluse regions) and in Spain, galerías or minas. Figure 2 includes a diagram representing the relations between climate and technique, which have led to the invention of the khattaras throughout the world (Labbaf Khaneiki 2019).

2.2 The components of khattaras

The khattara system is divided into two parts: collection and distribution (Fig. 3).

- The capture: The groundwater is collected by a channel of several kilometres in length, which is slightly sloped, in the upstream part of the system. This system collects the water from the aquifer and brings it towards the open surface. This channel is equipped with several vertical wells that are used for the maintenance and ventilation of the khattara.

- The channel: The slightly inclined underground channel brings water from the upstream wells to a point in the ground located downstream (the channel acts, in part, like an underground drain to collect water). The work consists of a channel of a variable section (its width varies from 50 cm to 80 cm and its height ranges from 90 cm to 150 cm). The length of the channel can vary from a few hundred metres to several km.
- The wells: The khattara include a series of vertical wells between the ground surface and the channel, spaced 5 to 40 m apart, depending on the nature of the terrain. At the start of the khattara, the wells are used to remove the cuttings. Once in operation, these wells are used as access points for the removal of excavated debris accumulated during maintenance and for the ventilation of the channel. The depth of the wells varies from a few metres to ten metres, and their diameter varies from 0.5 m to 1 m.

2.3 The genesis of a khattara

The making of a khattara requires the water table to be at a higher level than that of the fields that will be irrigated (Remini and Achour 2008; Remini, Achour, and Kechad 2010; Remini, Achour, and Albergel 2011; El Faiz and Ruf 2010).

The direction of the khattaras depends on the topography of the region, but it is always oriented parallel to the direction of the flow of the water table, from upstream to downstream, where the land to be irrigated is located. Khattaras have been built going from downstream to upstream in almost all areas where the technique has been utilised.

² In Iran, the khattara system is called *qanat*. According to Goblot (1979), this term is of Akkadian origin. It would come from the root *qunu*, which designated a reed. It then became *qanat* in Hebrew and *qanya* in Aramaic. From there, came the Latin word *canna* (perhaps itself behind both the words *sugar cane* and *channel*). We can also say that the term *qanat* is of Arab origin, and that it means *leak channel* or *irrigation channel*, or *conductive pipe*.

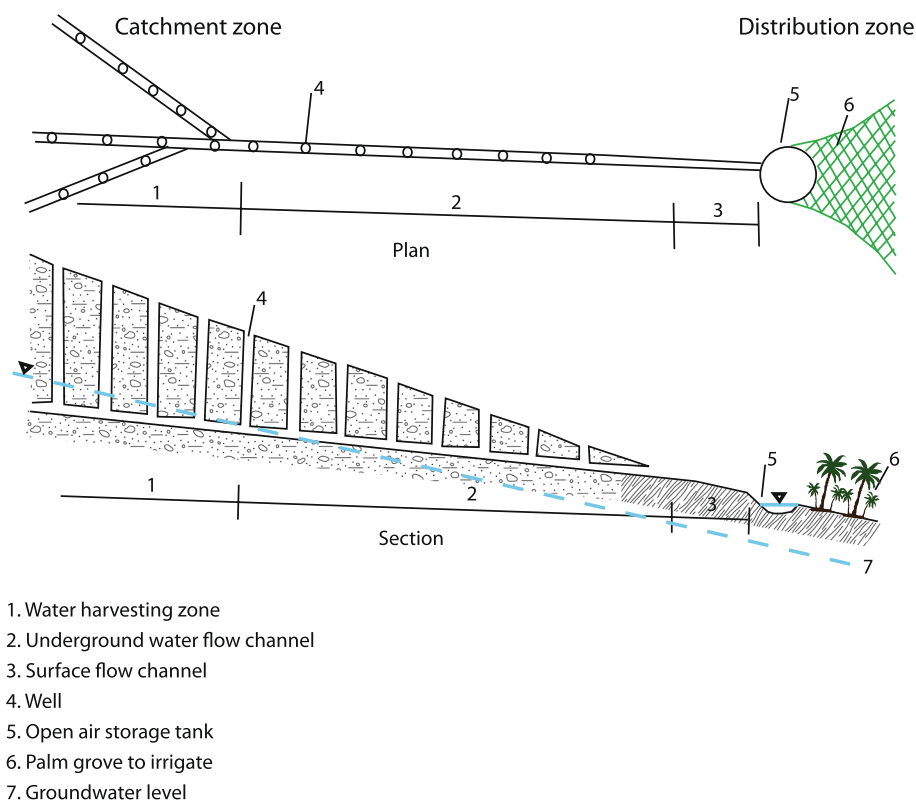


Fig. 3 The components of a khattara, (a) plan view and (b) sectional view (Source: the authors)

Before a khattara is built, an exploratory well is dug at the highest point to ensure the presence of an underground water table and to know its depth. Figure 4 describes the steps involved in the digging of a khattara.

When the first two wells are dug, they are connected to a lower portion of the system by a channel (Fig. 4a). A third well is then dug that will, in turn, be connected to the second well by another channel. The procedure thus continues until the last well is built, where the piezometric level of the water table is reached (Fig. 4b, c).

Once the khattara has been built, the water flows into the channel continuously towards the oasis; hence, there is generally a basin of accumulation at the exit of the khattara so the water accumulating during the night serves for irrigation, which occurs during the day. Low rainfall during drought years can cause a drop in the piezometric level in the wells of the khattaras' head. In this case, the water supply dries up, and the irrigation of the palm grove is no longer guaranteed. Consequently, when this scenario occurs, the workers extend the channels upstream so that the head of the khattara is again below the piezometric level.

The upper opening of each well is closed by a roof or surrounded by an earth ring from the excavation, thus acting as a protection against silting.

The instruments used to build a khattara are simple and traditional. Workers use picks, spades, and baskets to dig in the channel while a pulley and a winch make it possible to bring up the spoils that result from the digging or cleaning, thanks to a rope at the end of which can be hung a seal (*dlou*) drawn by the workers, a donkey or a dromedary (Fig. 5).

At the start of the digging, the internal dimensions of the canal do not exceed 1 m in height and 0.5 m in width. These reduced dimensions have no other use than to avoid excavating a significant weight of earth. However, progressively, the canal's roof moves away from the surface of the water.

2.4 Water distribution rights

The distribution of khattara waters follow customary laws of distribution called 'water rights'. These rights have been based on the work provided by the user during the construction of the khattaras and have been transmitted from one generation to another. These rules have continued to govern the provision of maintenance and upkeep services for the khattara resource. The holder of a water right can make use of that right, sell it or rent it for a fixed period; that right can also include other users (Ouhssain 2004; Plusquellec and Bachri 2013).

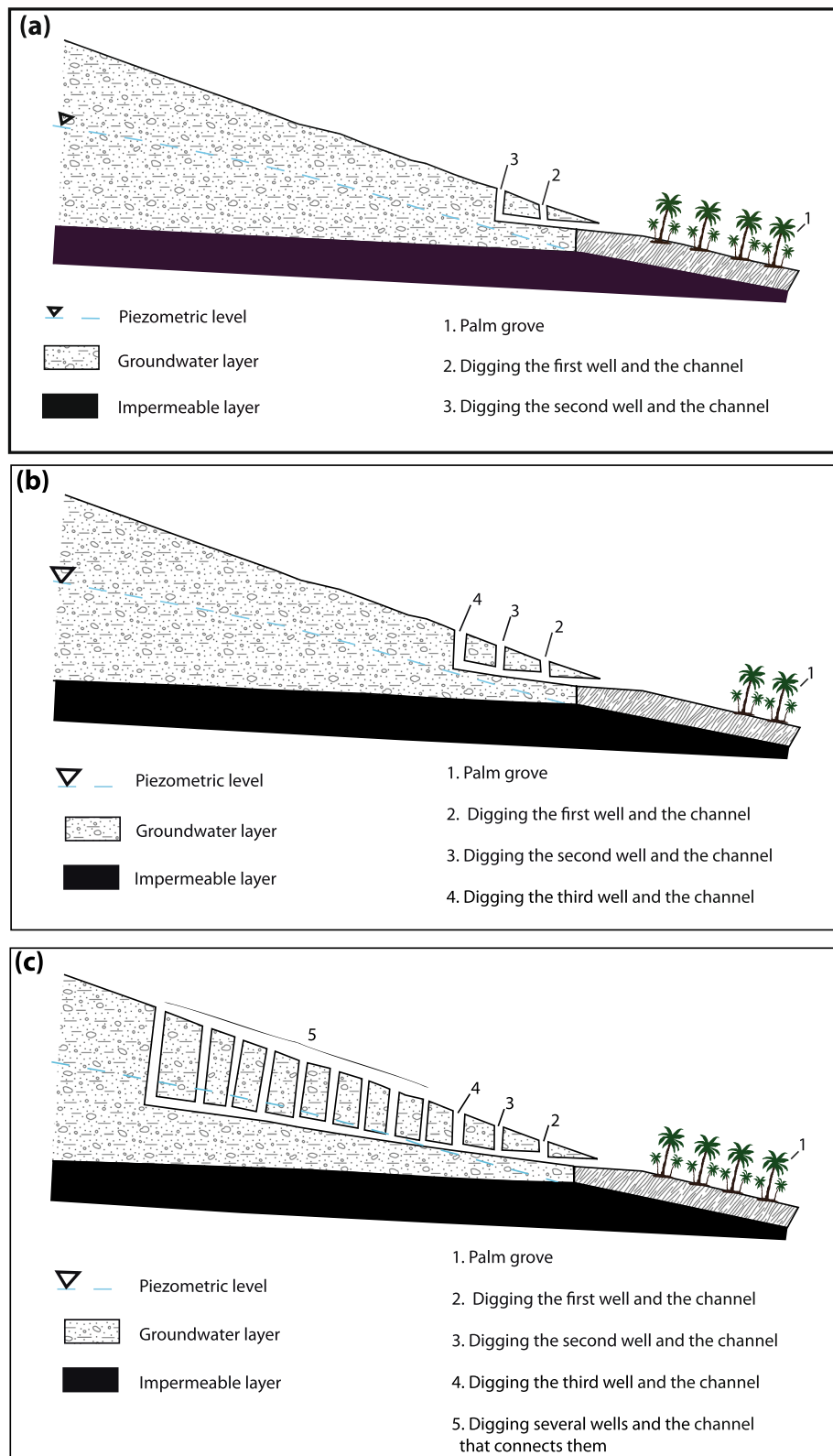


Fig. 4 The stages in the genesis of a khattara. **a**, stage 1; **b**, stage 2; **c**, stage 3 (Source: the authors)

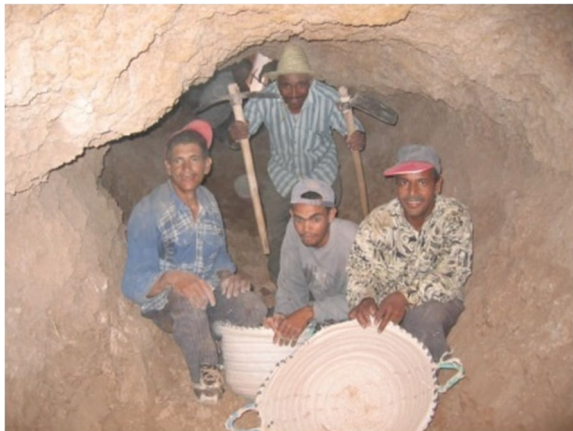


Fig. 5 Photo of khattatars, builders of khattaras (Source: the authors)

door at the entrance of the douar is used to estimate the duration of water sharing. The hydraulic clock system, or *Tanast* (pierced bowl placed in a container containing water), consists of filling the *Tanast* and letting the contents flow after a specific duration (approximately 45 minutes). This duration represents the unit of measurement for the distribution of water. Each time the *Tanast* sinks down, a knot is formed. This knot lets people know the status of the distribution. A graduated stick is also used as a measuring instrument. The water level is measured at a specific location in the water storage tank, and the duration is converted to a water level in the tank. For a given irrigation duration, the height of the water in the basin varies according to the flow. Today, almost everyone uses a watch, and the water dispensed is measured in hours and minutes (Fig. 6).



Fig. 6 The hydraulic clock system or *Tanast* and the graduated stick used as a measuring instrument for the distribution of khattara water (Source: the authors)

The amount of work provided is converted into shares. In the predominant water distribution system, a unit of use is called *Nouba* or *Fardia* and corresponds to a duration of 12 hours during which the shareholders benefit from the entire flow of a khattara; this distribution system has helped to avoid conflicts in the Tafilalet region. The distribution of water is ensured between the beneficiaries under the control of the sheikh. It is the latter who organises maintenance and upkeep of the khattaras, reminding the holders of the rights about it³ whenever necessary.

The rules governing the supply of water and water sharing vary across areas. The length of the shadow of the

Maintenance work entails cleaning, unblocking, sealing leaks, etc. For this type of work, the right holders provide the necessary workforce to the dispatchers (sheikhs). In the case of masonry, concrete, or upstream extension works, the formula adopted consists of creating a bottom for the body of the khattara, and the contribution of each user depends on the shares he or she owns (Ouhssain 2004; Ben Brahim 2003).

Currently, the fragmentation of water rights and the complexity of distribution rules explain the multiplication of transactions and exchanges between right holders (Kikudji et al. 2005).

2.5 Khettaras of the Tafilalet region

The plain of Tafilalet corresponds to an elongated north–south depression surrounded by low hills (from 700 to 1,050 m in altitude). It is crossed by two *Wadis* that flow from the north to the south: the Ziz and the Rheris.

³ The status of a khattara's right holder is determined by the possession of a water right (water time) based on a specific irrigation network, which can be acquired through inheritance or purchase. The value of participation in the construction of the khattaras determines water rights associated with the khattaras.

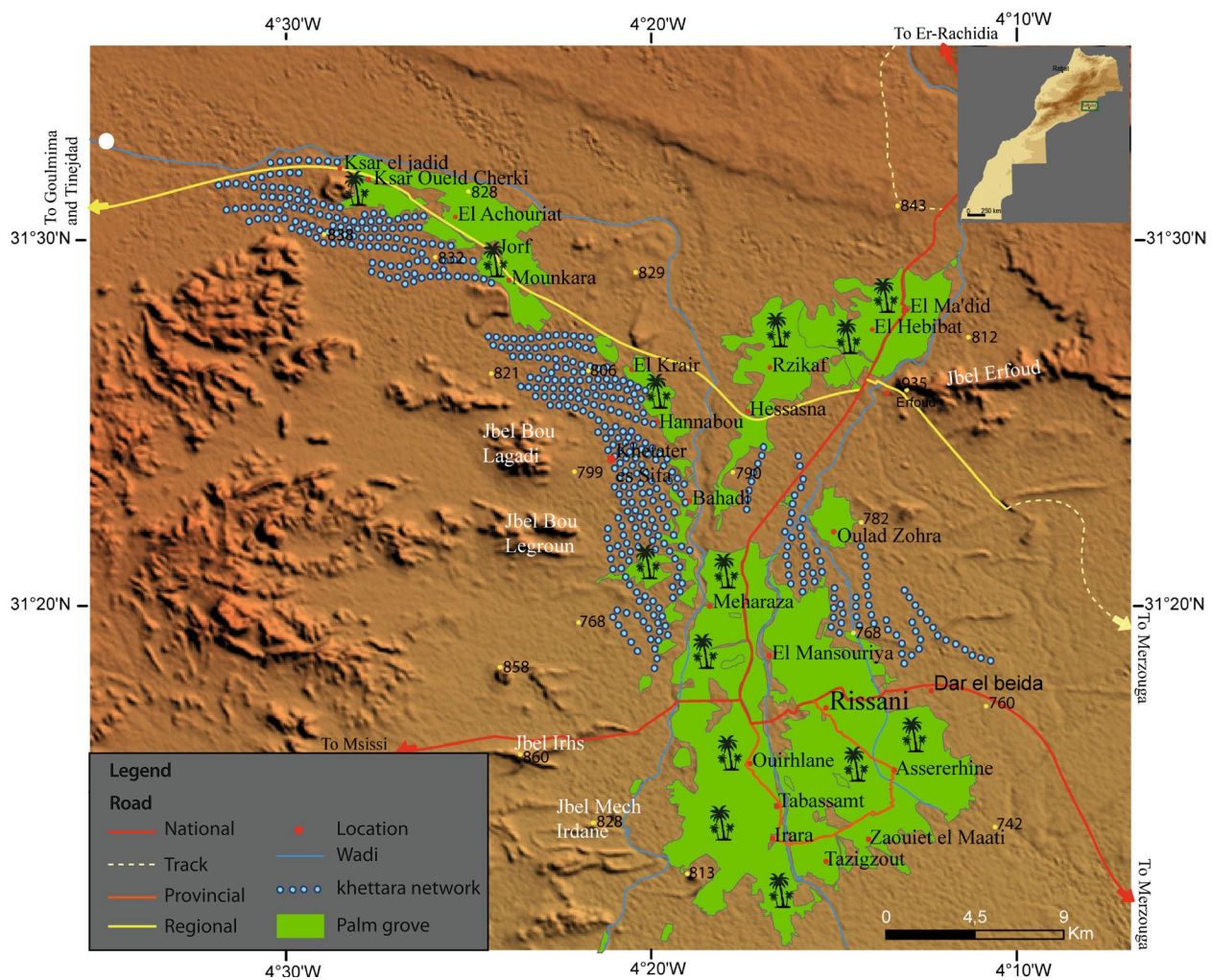


Fig. 7 Distribution map of khetaras in the plain of Tafilalet (Source: the authors)

The centre of the plain is occupied by the palm grove of Rissani, which extends over 20 km in length and 15 km in width and constitutes the largest palm grove in Morocco. The northern part of the plain is formed by the palm groves of Erfoud and Eljorf. Figure 7 shows the organisation and locations of the khetaras in the oasis, as well as the infrastructures (road and track) and the territories (e.g., villages, ksour, etc.) included in the study area.

The waters drained by the Ziz and the Rheris come from the Eastern High Atlas in the North, are replenished by the seasonal floodwaters of the local wadis and are stored and exploited in the upstream section. This exploitation has been developed since the construction of earth dams, or *Uggug*, which have left behind the irrigation canals, or *Saguia*.

The water flowing into the *Wadis* during the rainy period infiltrates into the permeable Quaternary formations and contributes to the supply of the water table.

The existence of this groundwater has enabled local populations to develop various techniques for the exploitation of water for both drinking and irrigating palm fields.

Khetaras have been the most ingenious and effective technique for acquiring water (Ben Brahim 2015). The distribution of khetaras in the plain of Tafilalet has been irregular. The right bank of the Rheris *Wadi* presents the greatest concentration of khetaras in Tafilalet and even in Morocco as a whole.

Throughout the plain, just over 380 khetara-based networks have spread along approximately 500 km of channels. Traditional irrigation systems have been extremely vulnerable in the Tafilalet plain. This vulnerability has been the result of a combination of factors, including drought and a drop in the piezometric level caused by the overexploitation of groundwater. As a result, several khetaras are no longer available for use. Scholars have

Table 1 Distribution of operating khattaras by localities in the plain of Tafilalet

Locality	Number	Percentage
Fezna- Jorf- Hannabou	59	39%
Siffa	34	23%
Oulad Zohra- Oulad Youssef	24	16%
Rissani- Taouss	33	22%

shown that (JICA 2003; Jarar Oulidi, Benaabida, and El Jaafari 2004), of the 386 khattaras listed in the area, 321 have experienced a permanently decreasing flow, moreover, 24 khattaras have been abandoned due to overexploitation of the water table linked to the use of motor pumps.

Indeed, the khattara process relies on opportunities presented by the water table: khattaras keep the water level constant and collect variable flows based on the water table's capacity. Motor pumps impose a flow and thus cause variations in the piezometric level of aquifer systems. When that level declines, the khattaras' galleries that capture water cannot be over-drilled as easily and quickly as they are with motor pumps, which cause the khattaras to become dry. According to the census of The Tafilalet Agricultural Development Regional Office (ORMVAT 2006), the number of khattaras still in operation today is approximately 150 (Table 1).

Groundwater catchments by khattaras are naturally vulnerable to the influence of overexploitation when pumping occurs within the same aquifer; for example, in the alluvial aquifer that has been exploited in Tafilalet, 'khattaras and motor pumps cannot coexist and in the event of competition the latter necessarily prevail' (Margat 2001; Jarar Oulidi, Benaabida, and El Jaafari 2004; Spoerry 2007).

The khattara system was implemented in the Tafilalet basin towards the end of the 14th century; it is made up of 300 km of a network of impressive channels (Lightfoot 1996b). Most likely, the khattara technology first arrived in Morocco from the Middle East after the Islamic Revolution (Lightfoot 1996b).

Gautier (1964) stated that the technique used to build khattaras was probably introduced in Tafilalet by the Zenites, who have greatly contributed to spreading irrigation techniques in the Saharan regions. According to this hypothesis, the first khattaras built in Tafilalet date back to the seventh century.

On the other hand, the Arab chroniclers, travellers, and geographers who described Tafilalet in the 11th or 16th centuries did not mention the existence of khattaras (Ben Brahim 2003). The first traces of excavation of draining channels of the khattara type in the Tafilalet

**Fig. 8** Photo of the khattara system in the Tafilalet Valley (Source: www.Waterhistory.org)

region have been well documented and date back to the 16th and 17th centuries (Oulad Youssef and Hannabou). The khattaras found in Siffa date back to the 18th century (1730), and finally the most recent khattaras are found to date back to the reign of Moulay El Hassan (20th century) (Ben Brahim 2003).

The total number of khattaras in the region is 570 (including the abandoned ones), of which only 304 are currently in operation. The area covered by khattaras is approximately 16,000 h, with a total network length of 855 km. The average debit is approximately 700 L/s across all khattaras. Most of the khattaras have been located north of Tafilalet, especially on the right bank of the Rheris *Wadi* (Figs. 7 and 8).

2.6 Valorisation of khattara sites

For 30 years, khattara systems have experienced increasing difficulties and have eventually disappeared (El Faiz 2002).

Khattaras not only constitute a way of extracting groundwater but also a way of representing the culture, history, and unique knowledge of their builders. Khattara systems can be considered to constitute a global heritage because of their unique history, which reflects the social and cultural background of the communities that have relied on them (Abudu et al. 2011).

In the past, the rank and value of people were judged according to the amount of water their ownership rights allowed them to obtain from the khattaras; this

arrangement created a social hierarchy among right holders. The location of households used to be a good indicator of the social or economic status of its residents (Bonine 1989; English 1998; Abudu et al. 2011), and this specificity shows the sociocultural value of this heritage.

Scholars have proposed that the khettaras constitute an ingenious agricultural heritage system because of various reasons, which Jomehpour (2009) illustrated as follows:

- Khettaras sustain food and livelihood security;
- Khettaras support both biophysical and social/cultural diversity;
- Khettaras are efficient systems that minimise water consumption and improve water and crop quality;
- Khettaras maximise benefits (economic, social, global environmental, livelihood);
- Khettara systems are resilient and adaptive (they use Indigenous knowledge and wisdom in identifying solutions to critical environmental constraints);
- Khettara systems are historically unique and may be considered global heritage sites (intrinsic global benefit);

Khettaras are elements of the sociocultural heritage of oases, which it is important to safeguard. However, drought and technical and social problems have threatened the future of this heritage. Faced with the phenomena of land fragmentation and rural exodus, families have sought to ensure less access to water resources and have dug increasingly deep wells so as not to depend on others. However, poor families have not been able to resort to this strategy, and families who have abandoned their fields have participated in the degradation of palm groves.

Despite how ancient they are, khettaras present interesting characteristics for the contemporary development and durability of oasis systems. Khettaras are first and foremost a mode of water supply that is both economic and ecological. Indeed, once the initial investment has been made, the water is transported to the oasis by gravity without the need to spend money and fossil energy, in contrast to water motor pumps. These systems of drainage and filter galleries (khettaras or qanats) have been models of sustainability from both an environmental and exploitation point of view (Martinez Medina, Gil-Meseguer, and Gomez-Espin 2018).

Therefore, it is justified to pay attention to khettaras in today's regional development efforts. The preservation of this heritage has been a concern in Morocco (Agricultural Development Regional Office [ORMVA], Hydraulics, Water and Forestry, Southern Agency, Social Development Agency, Oasis Sustainable Territorial Development Program) but also for international

organisations (United Nations Educational, Scientific and Cultural Organisation [UNESCO], United Nations Development Programme (UNDP), Food and Agriculture Organisation [FAO]), which have launched programs to safeguard the old agricultural systems that present in the oases of southern Morocco. The agronomic actions behind the rehabilitation of khettaras have been designed in the face of increases in the price of water in order to increase farmers' incomes and integrate these networks into the circuits of a market economy.

Many agricultural projects have been implemented in the Tafilalet region by the government and nongovernmental organisations (NGOs), such as the International Fund for Agricultural Development (IFAD) and the Japanese International Cooperation Agency (JICA).

The rural development project that has been implemented in Tafilalet and the Dades Valley has been recognised by the IFAD, the Islamic Development Bank, the Organisation of the Petroleum Exporting Countries (OPEC) Fund for International Development, the Government of Morocco, and certain beneficiaries (in the form of working days). It has been implemented by the ORMVA in Tafilalet and Ouarzazate. Protecting natural resources and preventing their degradation, enhancing basic infrastructure and social services in rural areas, and developing local institutions and organisations have been some of the objectives of this project (IFAD 2006).

The Japanese International Cooperation Agency's (JICA) project 'Study of rural community development through khettara rehabilitation in the semiarid regions of the southeast Atlas' has the following objectives (JICA 2003 and 2012):

- The establishment of a master plan for the long-term development of rural communities through khettara rehabilitation;
- The preparation of a feasibility study for khettara rehabilitation works in priority sectors;
- The transfer of planning methods, techniques for carrying out the work, and management to the ORMVA office staff;
- The transfer of production techniques to local populations.

JICA collaborated with an association for the defence of khettaras created in 2001 by ORMVA and some farmers in the region (JICA 2003 and 2012).

The specificity of oasis ecosystems was officially recognised on November 10th, 2000, when the oases of southern Morocco (including Tafilalet) were classified as a 'Biosphere Reserve', a status attributed by UNESCO (Sperry 2007; Garbati Pegna et al. 2017).

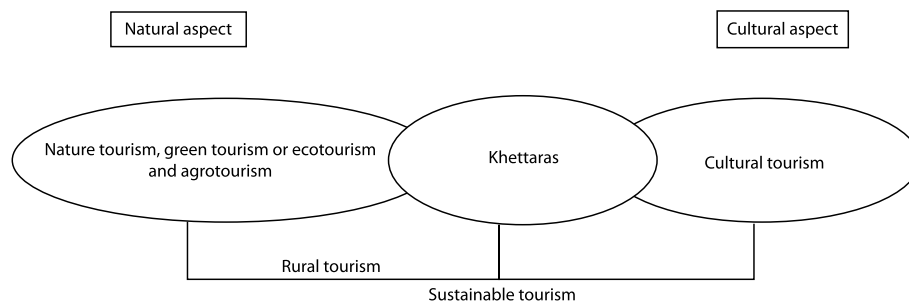


Fig. 9 The contribution of khetaras to different types of tourism (Source: the authors)

2.7 Promotion of khetaras as sites for touristic activity

The khetaras can allow the develop of cultural tourism because of their cultural value. Such tourism is motivated by the broadening of horizons (an intellectual pursuit) and the quest for knowledge and emotions through the discovery of the khetaras, their history, their genesis and the social aspect of this heritage and the oasis territory. Moreover, because khetaras are ‘open air’, and visiting them requires tourists to be out in a natural setting, tourists who seek to discover these khetaras participate in nature tourism in a highly rural environment that links the khetaras to rural tourism.

The exploration of khetaras in the oasis environment is also strongly related to green tourism or ecotourism, entailing ‘the nature and landscape values that would more directly specifically describe the frequency of rural areas far from cities’ (Bétéille 1996).

The khetaras have constituted an important source of water for the oases of southern Morocco, for local agricultural production and for subsistence; this aspect of khetaras has been more or less closely linked to agrotourism in the way it has promoted local products (Fig. 9).

The short distance between Morocco and Europe has been an undeniable asset in the development of tourism.

The potential for the development of touristic attractions in southern Morocco is great: there are well-preserved Kasbahs, traditional oases, modern architectural works (land artworks by Von Hannsjorg) at the Marha plain, and vast spaces, deserts, and mountains for hikes (Sadki 2007; Aït Hamza, Faskaoui, and Fermin 2010; Jouve 2012; Bouaouinate 2016; Abioui et al. 2018). Another particularity of the Tafilalet khetaras is their location halfway between two famous tourist sites, the gorges of the Todghra and the Merzouga sand dunes. Hence, tourism tends to replace certain activities that have been in crisis, such as agricultural or mining activities (Violier 2013).

Many domestic and foreign tourists visit this region each year because it boasts a rich heritage, historical

relics, natural beauty, oasis strips in the middle of the desert, clear skies year-round, sharp colours, bare landscapes, adobe architecture, sand dunes, and the traditional hospitality of the locals (Aït Hamza, Faskaoui, and Fermin 2010).

The area is a prestigious tourist destination with remarkably rich and diverse cultural sites and landscapes as well as an infrastructure that has begun to value this cultural heritage in tourism development policies (Strategic vision for tourism development ‘vision 2020’) (Bouaouinate 2016).

On the tourists’ demand side, there has been growing interest in the desert, and the khetara irrigation system has been listed in guides and touristic maps; however, few guides can explain how it works (Cournoyer 2004; Spoerry 2007; Bouaouinate 2016). Moreover, most tourists who cross over into the region and see the heaps of cuttings accumulated at the edge of khetara wells wonder what they are (Fig. 10) (Spoerry 2007). The khetaras are an ideal starting point for curious visitors to



Fig. 10 Photo of khetaras’ network organised for tourism in Tafilalet (Source: the authors)

discover oases, especially because people have advocated for a respectful discovery of local culture that is more integrated as part of the contemporary development of ecotourism.

To promote these systems that are in the process of being degraded and raise awareness among the general public as well as specialists, the Program for the Sustainable Territorial Development of the Oasis of Tafilalet (POT), implemented by the Directorate of Spatial Planning, UNDP, and other partners, has planned to build an ecomuseum around the theme of the khetaras in the Tafilalet region and integrate it into the circuit known as 'the *Majhoul* Road'. According to the president of the Fezna rural commune (Eljorf region), studies on the establishment of the ecomuseum have been completed, and a land plot has been made available for its construction; however, the budget for the construction has yet to be established by the project's different partners (personal communication, February 12, 2019).

The purpose of the *Majhoul* Road, according to this program, is to promote sustainable tourism in the region by making rational and sustainable use of the natural resources of the Tafilalet Oasis while incorporating a localised economic development dimension.

The conceptualisation of this ecomuseum is based on the presentation of khetaras as a symbol for the appropriate use of resources and the relationship between cultural heritage and sustainable development. The Living Ecomuseum of Khetaras is a practical museum organised on a regional level, which people experience through a journey of discovery and travel. Visitors undertake a learning journey through various types of explanations about tunnels, water management systems and oases via screens that present information and documentation; the visitors also meet with local people and encounter art, folklore, music and traditions (IPOGEA 2009–2010).

Hence, it is anticipated that the support for this ecomuseum will have a great impact on the natural environment as a tourism resource and a source of attraction for national and international tourists. As local development tools, such community museums promote cultural tourism and help to place pre-Saharan oases and mountain spaces on the regional tourist map (Bouaouinate 2016). Local populations have emerged as players in heritage and tourism dynamics (Peyrache-Gadeau, Duval, and Oudada 2013). Some community museums in mountainous or oasis regions, such as the Aït Iktel Museum in Ghoujdama or the Oasis Museum in Ksar el Khorbat in Tinjdad, have used a portion of their revenue to fund development initiatives pertaining to the supply of drinking water, the construction of an irrigation canal, village electrification, ksar restoration, the construction of a pre-school, and so on (Bouaouinate 2016).

Inhabitants in the region should be concerned with maintaining the oases of southern Morocco alive by using water resources thoughtfully. The rehabilitation of khetaras that began three decades ago, as part of the hydroagricultural development of the oases, has been financially and culturally expensive, and the results have overall not met expectations (ORMVAT 1985, 1987, 2005, 2006). The National Irrigation Board (ONI) and the ORMVAT funded, coordinated, and carried out interventions in the khetaras (ORMVAT 1985, 1987, 2005, 2006). Right holders have had a critical view of the rehabilitation work done on the khetaras, as they have frequently regarded that work as insufficient. The promotion of a tourism activity articulated around water and organic farming will undoubtedly contribute to the sustainable development of these oases. This type of tourism must be developed by and for the local populations as part of the safeguarding and enhancement of oases and in line with the guidelines of sustainable tourism. For example, Iran has had successful experiences with the exploitation of khetaras for tourism purposes in the underground city of Kish Island and the Mahan Arg in Kerman (Moayedfar and Fatemi 2021).

Furthermore, in 2016, UNESCO designated the traditional Persian khetaras as part of the world's cultural heritage. Given that the khetaras have constituted a cultural, historical, and ecological heritage, they can be integrated into geotourism activities and provide opportunities for sustainable tourism planning. They are intrinsically linked to the living environment of semiarid areas and fit with ecotourism initiatives as they combine with the natural elements that are being promoted by the Iran Cultural Heritage, Handicrafts and Tourism Organisation (ICHTO) (JICA 2018; Moayedfar and Fatemi 2021). The aqueduct—its structure and function—has been an attractive destination for many tourists, especially geotourists and ecotourists (Moayedfar and Fatemi 2021). The khetara systems in Tafilalet are eco-friendly and can be used as part of a tourist attraction (JICA 2012).

Agrotourism includes tourism activities that complement agriculture. It connects agricultural producers with tourists, allowing the latter to discover the agricultural environment through immersion and information. Agrotourism must be accompanied by serious design and the production of specific means of accommodation (Vafiadis, Xristos, and Leonidas 1992; Geotee 2000; Gousiou, Spilanis, and Kizos 2001; Abioui 2016). A guide of the palm plantation ensures visits around the water resource and explains the distribution of water, the oasis flora and fauna and the cultural and architectural heritage. At the hosts' place, oasis food products are highlighted. Rural tourism is necessary to maintain, protect,

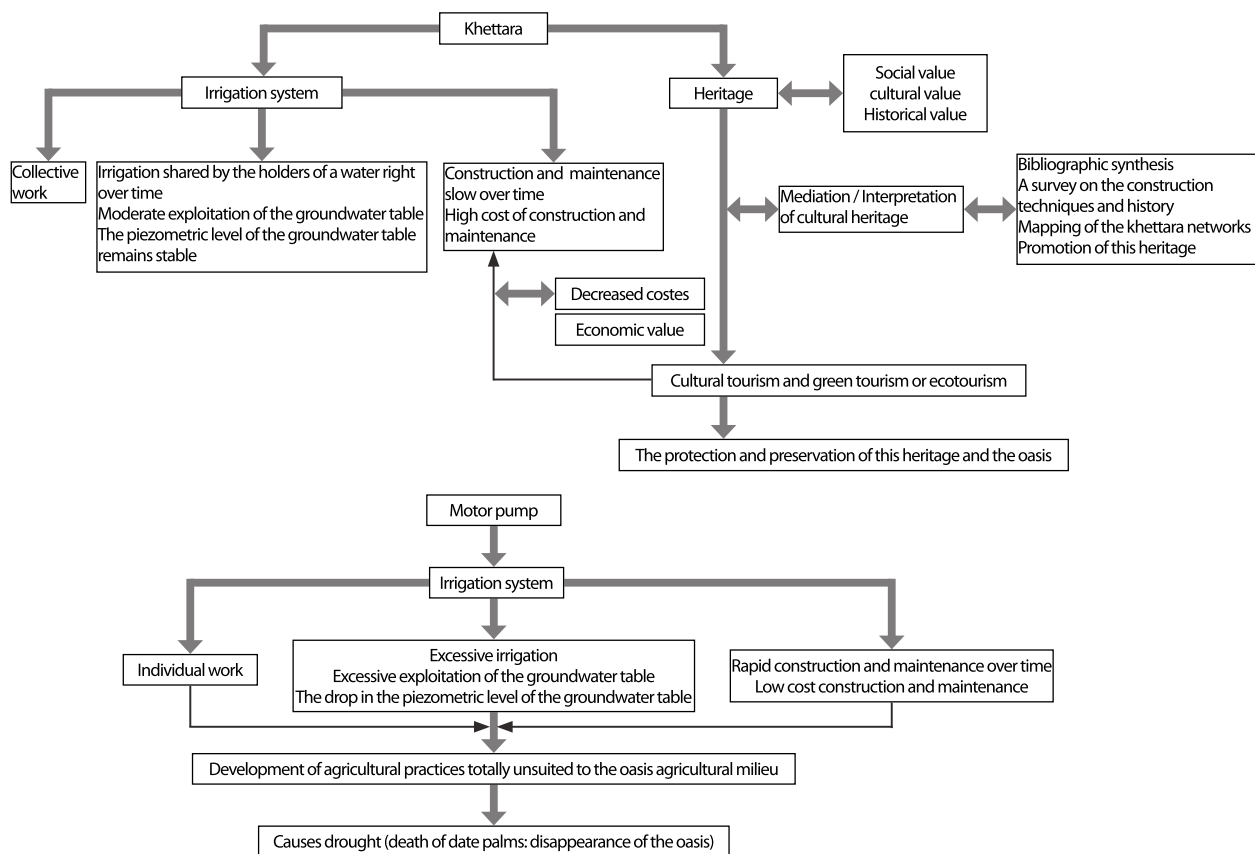


Fig. 11 A comparative summary of the motor pump system and the khattaras (Source: the authors)

and enhance historical monuments and practices that come from our past and constitute our heritage.

A sure planning for the abilities of the qanats can certainly affect the tourism prosperity in those regions, and boosting tourism (Moayedfar and Fatemi 2021).

The analysis conducted by Moayedfar and Fatemi (2021) on the experience of khattara tourism development in Iran highlighted some of the applications proposed in this paper as follows:

- Launch efficient/flexible marketing promotional strategies to create confidence in the target market through special events, billboards, trade shows, TV programs, public relations events, and advertising, which are the best tactics for promotion.
- Create a museum about khattaras (qanats) to provide tools related to this technology and to show the different dimensions of khattaras.
- Create the right advertisements to introduce tourism attractions in the history of khattaras.
- Introduce the technology used by the khattaras to tourists in the form of advertising and virtual networks.

3 Conclusion

In recent years, the system of khattaras has competed with more modern systems, such as motor pumps, drips, etc., in a context of repetitive periods of droughts. Motor pumps have threatened the survival of the khattara system and the oasis (Fig. 11). As a result, the network of nonproductive khattaras has been abandoned. The khattara heritage has therefore disappeared and has been difficult to transmit to future generations. Khattaras constitute a heritage based on know-how and fosters the sustainable development of rural hydraulics; they also constitute a way to geoeeducate people. They represent a social organisation and customary institution. The khattaras represent a system of inventiveness that has marked the history of humanity; they have allowed the inhabitants of arid and Saharan regions to survive extreme environments. They constitute an irrigation system that has allowed oasis farmers to benefit as much as possible from the water table (in areas in which evaporation is almost zero) without requiring the use of a pump or an energy source.

Most studies on khattaras have focused on their structural, historical, archaeological, and social dimensions,

as well as on water quality aspects. However, few studies have focused on the heritage capacity of these systems and on their potential for sustainable tourism development. This paper focuses on new issues and ideas to foster the valorisation of khettaras to further stimulate interest in studying the heritage tourism potential of khettaras in the future.

The khettaras are valuable artifacts that have earned recognition as cultural heritage based on its social manifestations, construction methods, and cleaning up processes. The social, historical, and cultural value associated with the presence of khettaras in arid areas over time has served as evidence of the oasis community's social organisation and human capacity to adapt to the environment. This capacity pertains to the economic and environmental role of the khettaras in the oasis environment. Moreover, the intangible value of khettaras is based on the transmission of knowledge and tradition (knowledge about water sharing and construction and maintenance techniques); the socioeconomic value of the khettaras is linked to the development of a social economy around them. Khettaras are thus valuable resources that need to be preserved through the development of sustainable tourism.

Tourism based on khettaras, in which tourists enjoy learning about the technology they use and experience their structure, beauty and natural and geological features, can lead to sustainable development and enhance the attention paid to this cultural structure (Moayedfar and Fatemi 2021). Khettaras have frequently been underestimated, but they have remained a relevant part of the history of how humans have faced daily challenges. The preservation of khettaras starts with the public knowing about them and public authorities supporting them (Carrion and Fornes 2016).

Based on the inventory presented in this paper, which describes and maps out the main khettara network sites in the Tafilalet region, we expect that these cultural and historic heritage could be promoted as tourism attractions with appropriate management.

The interpretation of the khettaras is an important tool for the management of this heritage as part of a strategy for the sustainable development of tourism. The description and explanation of the history of khettaras, the components of khettaras, the genesis of the khettara system and the water distribution rights based on this khettara system will help visitors understand and appreciate that khettaras are significant for our heritage and that it is important to protect them for future generations. The history of khettaras and of the revolution the khettara system has initiated in ancient irrigation techniques can play an important role in

educating and explaining to visitors the history of irrigation and the different styles of irrigation systems. It is therefore necessary to stimulate interest for this heritage and attract the attention of curious visitors to it. Information presented to the public should emphasise the scientific interest (historic) in these systems, the ingenuity of these systems in managing water, and the role they have played over time in the preservation of oases. Cultural tourism guides should be trained to interpret this kind of system and ancient techniques of irrigation. The sites should be integrated in tourist circuits such as 'the *Majhoul Road*' and explanatory panels should be installed in the vicinity of the sites. Moreover, brochures in multiple languages should be made available to attract curious and avid visitors, which would generate additional economic resources for the region, ultimately ensuring the protection and preservation of this heritage and the oases.

Abbreviations

DAT: Direction de l'Aménagement du Territoire (Directorate for Land Use Planning); FAO: Food and Agriculture Organisation; IFAD: International Fund for Agricultural Development; IPOGEA: Traditional Knowledge Research Center, in Matera; JICA: Japanese International Cooperation Agency; MATEE: Ministère de l'Aménagement du Territoire, de l'Eau et de l'Environnement (Moroccan Ministry of Land Use Planning, Water and the Environment); NGO: Non-Governmental Organisation; ONI: Office National des Irrigations (National Irrigation Board); ORMVA: Office Régional de Mise en Valeur Agricole (Agricultural Development Regional Office); ORMVAT: Office Régional de Mise en Valeur Agricole du Tafilalet (The Tafilalet Agricultural Development Regional Office); OPEC: Organisation of the Petroleum Exporting Countries; POT: Program for the Sustainable Territorial Development of the Oasis of Tafilalet; UNESCO: United Nations Educational, Scientific and Cultural Organisation; UNDP: United Nations Development Program.

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Authors' contributions

All authors contributed to the conception of the study, performed the data and map analyses, drafted, and wrote the manuscript. M. B., M. A., and M. H.: Writing - Original Draft, Methodology and Visualisation. J. M-F: Validation, Writing - Review & Editing. All authors read and approved the final manuscript.

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Availability of data and materials

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Declarations

Competing interests

The authors declare that they have no competing interests.

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