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Water resource management techniques in Tunisia: Towards sustainable agricultural use

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Abstract

Tunisia is a marginal country hydrologically and it has adopted a number of distinctive methods of water management for agriculture. The central region supports modern dam irrigation, whilst traditional rainwater harvesting is practiced in the south. These contrasting techniques are described and evaluated in terms of sustainability using empirical field data and secondary literature for two study sites. Research focuses primarily on the physical environment, but socio-cultural and economic viability are also examined. Analysis indicates that traditional water management advantageously partitions the continuum dividing hazards and resources through subtle manipulation of the environment. A potentially hazardous environment is rendered secure by resourceful water management based on community action and cumulative knowledge. This practice minimizes community dependency and local economic imbalance. With dam irrigation, carrying capacity is established more forcibly by centralized control in order to place society within world markets. An almost total break from environmental variability is made in the short term, but this can lead to disequilibrium over longer durations. Additionally, the spatial and social distributions of development are uneven. In Tunisia, maintenance of traditional methods can reduce the negative impacts caused by modern programmes and support their positive characteristics. A mix of both methods offers a foundation to sustainable water supply in the new millennium.

Key words: Water Harvesting, Conservation, Recharge, Tunisia.

Techniques de gestion des ressources en eau en Tunisie : vers une utilisation agricole durable

Résumé

La Tunisie est un pays marginal sur le plan hydrologique et elle a adopté un certain nombre de méthodes distinctes de gestion de l'eau pour l'agriculture. La région centrale soutient l'irrigation des barrages modernes, tandis que la collecte traditionnelle des eaux de pluie est pratiquée dans le sud. Ces techniques contrastées sont décrites et évaluées en termes de durabilité à l'aide de données empiriques de terrain et de la littérature secondaire pour deux sites d'étude. La recherche se concentre principalement sur l'environnement physique, mais la viabilité socio-culturelle et économique est également examinée. L'analyse indique que la gestion traditionnelle de l'eau divise avantageusement le continuum qui divise les dangers et les ressources grâce à une manipulation subtile de l'environnement. Un environnement potentiellement dangereux est rendu sécurisé par une gestion ingénieuse de l'eau basée sur l'action communautaire et les connaissances cumulatives. Cette pratique minimise la dépendance communautaire et le déséquilibre économique local. Avec l'irrigation des barrages, la capacité de charge est établie de manière plus forcée par un contrôle centralisé afin de placer la société sur les marchés mondiaux. Une rupture quasi totale de la variabilité environnementale est opérée à court terme, mais cela peut conduire à un déséquilibre sur des durées plus longues. De plus, les distributions spatiales et sociales du développement sont inégales. En Tunisie, le maintien des méthodes traditionnelles peut réduire les impacts négatifs causés par les programmes modernes et soutenir leurs caractéristiques positives. Un mélange des deux méthodes offre une base pour un approvisionnement en eau durable dans le nouveau millénaire.

Mots clés : *Collecte de l'eau, conservation, recharge, Tunisie.*

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INTRODUCTION

In the arid and semi-arid region, countries such as Tunisia are facing increasingly more serious water shortage problems. Problems of water scarcity will intensify because of population growth, rise in living standards, and accelerated urbanisation which threaten the water supply in general and agriculture in particular and lead to both an increase in water consumption and pollution of water resources. Continuing increase in demand by the urban sector has led to increased utilisation of fresh water for domestic purposes, on the one hand, and production of greater volumes of wastewater, on the other. Agriculture in competition with other sectors will face increasing problems of water quantity and quality considering increasingly limited conventional water resources and growing future requirements and a decrease in the volume of fresh water available for agriculture.

The history of Tunisia reveals how the scarcity of water resource forced its inhabitants to deal with its unequal distribution within the country. As early as 130 BC, the Roman Emperor Adrian constructed a temple of water and a huge aqueduct to transfer water over 123 km from a spring located in the region of Zaghouan to the city of Carthage. In the early eighth century, the Arabic Dynasty of Aghlabides transferred groundwater and stored it in big basins to supply the new founded town of Kairouan. This concern for water still persists since it is required for development in all social and economic sectors.

Tunisia is situated to the south of the Mediterranean; it is bordered by Libya in the southeast, Algeria in the west (Fig.1). Tunisia's surface area is of 164,000 km², its coastline totals 1300 km, its average altitude is 700 m and its highest point is the Jebel Châambi (1540 m). Tunisia country share many common features in terms of climate, water and land resources and development issues. These include arid and semi-arid climate, limited water resources, agricultural development limited by water availability and high economic and social value of water (Gaaloul, 2011).

Rainfall in Tunisia is irregular: there are long dry periods and precipitation varies from year to year and from North to South. Average annual rainfall is between 500 mm to 1000 mm in the North, 300 mm in the Centre and 150 mm in the South (Figure 1). Dry periods lasting several weeks often occur during one season or can last over several consecutive seasons. The annual average rainfall is estimated to 36 billion cubic and is ranging from 11 to 90 billion cubic. Rainfall received in the North is highly variable from the rainfall received in the South, and often a transfer of water resources is needed from the North to the South. Average annual evapotranspiration is also high and water deficit is particularly significant from May to October. The annual evaporation varies between 1300 mm in the north to about 2500 mm and even more in the south.

Tunisia's geographical situation, bordering the Mediterranean on the east and north and stretching to the Sahara in the south, gives it an arid, diversified climate. The climate is varies from Mediterranean to semi-arid and arid, ranging from humid in the extreme North to desert-type in the extreme south. The climate is Mediterranean, ranging from humid in the extreme North to desert-type in the extreme south. In the north and along the coast, the climate is Mediterranean; inland and in the south it is semi-arid to arid.

The hottest month is August with a mean monthly temperature of 26°C, and a highest monthly temperature of 28.7°C. January is the coolest month having a mean monthly temperature of 10.7°C and a lowest value of 8.4°C. The mean annual temperature in Tunisia varies between 15°C in the North to 21°C in the South.

The climatic and geomorphologic characteristics define three major agro-ecological zones:

- The North, constitutes a sylvo-agricultural region (mainly forests and annual crops); its average rainfall is between 400-600 mm and its main topographic features are mountain pasturelands in the north-west and fertile plains in the north-east.

- The Centre, constitutes an agro-pastoral region (pasturelands and crops); its rainfall is between 200-400 mm, and its morphology is composed of a low steppe to the east with fertile plains interrupted by depressions and a high steppe with mountain pasturelands and plains.

- The South, with irregular rainfall of 100-200 mm, is characterised by its aridity and vulnerability of its soils to desertification. This area is pastoral with oases.

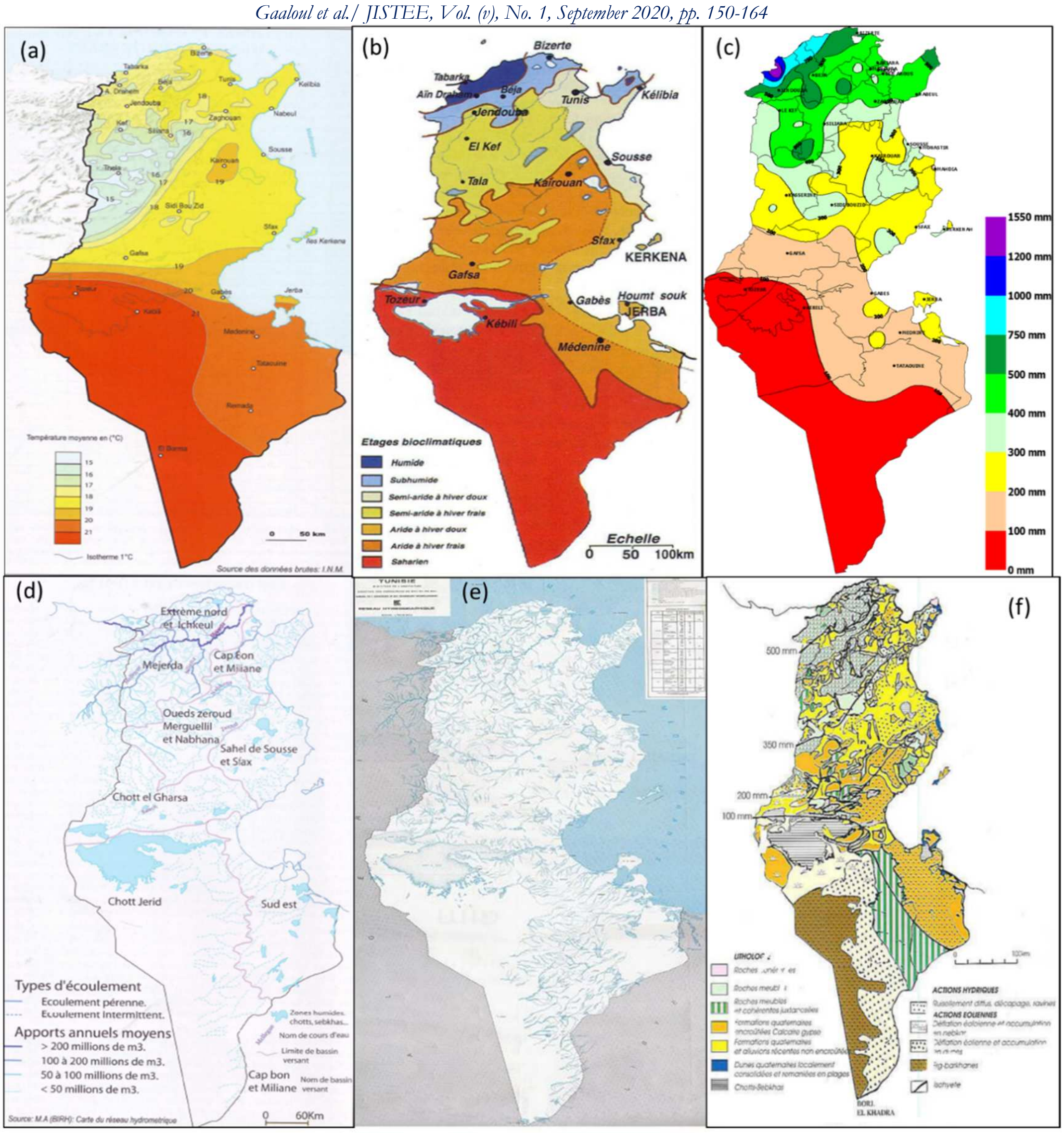

Fig. 1. Tunisia situation geographic and the network hydrographical (a) Temperature; (b) Bioclimatique, (c) Rainfall; (d) Dam, (e) Hydrographic network; (f) Erosion

The total population of the country is 9.6 million inhabitants (2004 census) with 61 % living in urban areas and 39 % in rural areas. The natural growth rate is 1.9 % (2004). Education has always been a priority sector, with a primary school enrolment rate of 100 %. Although the illiteracy rate is still high, it is decreasing progressively. Health standards have much improved as witnessed by the drop in infant mortality from 127‰ in 1970 to 42‰ in 2004.

Tunisia faces a number of convergent natural and anthropic factors, which account for the fairly advanced level of soil degradation. The main problems are water and wind erosion, and salinisation. The great challenge is to contain these problems whilst preserving the productive potential of the land. Preventive actions aimed at the rational management of land must be combined with curative actions to enable land improvement, rehabilitation and restoration through adequate management. The combination of Tunisia's varied bioclimate, ranging from humid to Saharan - and its geology offering different types of rock outcrops -, generates a fairly rich variety of soils. The soils are well differentiated by their fertility and sensitivity to degradation. Three major regions can be distinguished by the nature of their soils and the related cultivation systems (Souissi, 2001).

Northern Tunisia, a region with a sylvo-pastoral potential, has highly diversified soils:

- Acid soils on alternating clay and sandstone, non calcareous, shallow but quite rich in organic matter and relatively stable,
- Deep calcareous soils on marl slopes very sensitive to water erosion;
- Shallow soils on calcareous rock, located on tops of hills;
- Deep, stable and fertile soils of numerous more or less extended plains.

All suffer severe water erosion enhanced by slope cultivation and tillage, by overgrazing, and by inadequate rotations of rain fed and irrigated crops where the integration of animal husbandry is virtually absent. The failure to recycle organic matter (manure, straw) accentuates the impoverishment of soils in humus and leads to their physical and chemical degradation. Soils of irrigated plains risk chemical degradation - salinisation - due to irrigation with brackish water without sufficient drainage to leach out the salts. Central Tunisia is an agro-pastoral region dominated equally by the heavy soils of alluvial plains, which are mostly sodic, by the sealed skeletal calcareous soils of the large fans and by the deep and light soils, which were in the past occupied by rich pastures.

These different units are confronted with several problems: the expansion of tree cultivation on the sandy steppes which triggers wind erosion; the cultivation of natural and esparto grass pastures which leads to the reduction of pasturelands, and as a consequence to overgrazing; the excessive development of irrigated agriculture using degraded water derived from overexploited aquifers, which leads to the secondary salinisation of soils.

Southern Tunisia has a pastoral vocation and is characterized by arid, light soils vulnerable to wind erosion, dominated by the presence of gypsum. Olive growing and cereal cultivation in the southern steppes are the cause of desertification of the natural pastures; these by deflation become stone deserts, and by accumulation, sand dunes. Mean annual rainfall values can be exceeded by factors of two to twelve during short and intensive rainfall events producing runoff and causing soil erosion (695 to 6050 tons per km² and year). Annual soil losses are estimated at 23 000 hectares, of which 13 000 hectares cannot be recovered (Souissi, 2001).

Land suitable for cultivation in the north and center of Tunisia, located north of the 200 mm isohyets, are most threatened by strong and moderate erosion while the Center-East and Cap Bon are somewhat less threatened. In total 1.2 million hectares are affected by water erosion, representing 25% of the nation's land suitable for cultivation. In the South, an estimated 50% of the land, not included in natural deserts, faces desertification (accumulation of sand, surface scraping). In spite of the wide range of causes and effects often used to describe it, desertification is a well-defined process. It is triggered by changes in climatic and socio-economic boundary conditions of affected dry land systems. These changes cause the systems to enter an irreversible positive feedback loop of overexploitation of land. The final outcomes are land degradation and disruption of local economies. Desertification is an acute process that occurs at rates several orders of magnitude faster than purely climate-driven land responses.

Tunisia's physical and climatic diversity has had great influence on the way in which its natural resources are used, and this, in turn, has had an influence on the risk of desertification. In the south of Tunisia, the steppes are reportedly being destroyed by human pressure at a rate of 1% per year. Alfa grass or plant communities associated with it dominate most of the steppes in the south of Tunisia. Human activities are at the root of the main factors in soil and plant-cover deterioration: overgrazing, cultivation of natural grazing lands, eradication of woody plant species, and irrigation with brackish water accompanied by poor drainage.

The effect of such inappropriate use of natural resources tend to be amplified by physical factors, varying according to region in terms of vulnerability and sensitivity: water and wind erosion, increasing soil salinity.

Water Harvesting, Conservation and Natural Recharge

The term water harvesting refers to direct collection of precipitation falling on the roof or onto the ground without passing through the stage of surface runoff on land. It is sometimes used to describe the entire gamut of water harvesting. We shall use it here only in the specific sense (Rahman et al., 2017).

The term conservation has been widely used in different fields. Economists consider conservation as managing the resources in such a way that maximum human needs will be satisfied. The water conservation can be considered as prevention against loss of waste (Malekian et al., 2017).

Technically, this can be achieved by putting the water resources of the country for the best beneficial use with all the technology available in hand. As far as Tunisia is concerned, in most of the places, there is a rainfall during winters months and very little rain during other months.

The winters rainfall often comes in pattern, which leaves some drought period in between. For this drought period, conservation of water is necessary. Conservation of water in drought prone area will help in providing more irrigation for development of agricultural potential of these areas.

The term recharge refers to transfer of surface water to sub-surface aquifers. The natural recharge process is seasonal nature, but the exploitation of groundwater is continuous and is increasing every year. Groundwater recharge is an important part of the hydrologic cycle, in which water from the surface works its way into the subsurface, replenishing groundwater supplies. In nature, groundwater recharge is supplied by rain, snowmelt, rivers, lakes, and streams. While some surface water evaporates or works its way into another watershed, other water trickles through the earth, gradually meeting up with a supply of water below the surface. It can take a long time for groundwater supplies to build up, or they can be replenished very quickly, depending on a variety of environmental factors.

The natural recharge can be increased somewhat by proper land use (natural vegetation and choice of crops), land tillage practices (e.g. contour ploughing in sloping areas, terraces), the installation of check dams and weirs in surface waters, so as to raise the water levels therein and to divert water to adjacent spreading grounds. The guiding principle of all these measures is to hold up the water as long and as much as possible in order to give it more time for infiltration, rather than to let it run off directly. Most of these measures are also favorable for erosion control (Bear et al., 1999).

Artificial recharge, one of the oldest activities undertaken in the world to conserve rainwater both above-ground and underground, is as old as the irrigated agriculture in the arid and semi-arid regions. In the olden days, the recharge movement initiated by the local communities was aided and supported by kings, chieftains, philanthropists and by those who valued water and practiced conservation.

Artificial recharge is the planned, human activity of augmenting the amount of groundwater available through works designed to increase the natural replenishment or percolation of surface waters into the groundwater aquifers, resulting in a corresponding increase in the amount of groundwater available for abstraction. Although the primary objective of this technology is to preserve or enhance groundwater resources, artificial recharge has been used for many other beneficial purposes. Some of these purposes include conservation or disposal of floodwaters, control of saltwater intrusion, storage of water to reduce pumping and piping costs, temporary regulation of groundwater abstraction, and water quality improvement by removal of suspended solids by filtration through the ground or by dilution by mixing with naturally-occurring groundwaters (Asano, 1985). Artificial recharge also has application in wastewater disposal, waste treatment, secondary oil recovery, prevention of land subsidence, storage of freshwater within saline aquifers, crop development, and streamflow augmentation (Oaksford, 1985).

The United Nations Food and Agriculture Organization (FAO, 2002) is actively engaged in promoting three methods of recharge to shallow aquifers:

- water harvesting techniques ('run-off farming') by which water is stored in the root-zone and excess water percolates to the aquifers.
- water management in wetlands to provide over-season storage and enhanced recession flows to contribute to recharge and provide residual soil moisture for a dry season cropping,
- construction of small reservoirs, even on permeable soils, to store water but at the same time also to recharge the local shallow aquifer.
- The principles followed when applying aquifer recharge include:
- Ideally, recharge activities, including mechanized water harvesting techniques, should focus on the most favorable soil/aquifer situations and be combined with the overall resource management of the linked aquifer systems, at the watershed scale
- Full participation from the farmer's community, paying particular attention to the role of women, through involvement during planning, design, implementation, operation and evaluation of the system.

The investment should result in income in the short term. Water harvesting results in surplus production of grain or fodder. Artificial recharge should result in more water for irrigation and increased production

A variety of methods have been developed and applied to artificially recharge groundwater reservoirs in various parts of the world. Details of these methods, as well as related topics, can be found in the literature (Todd, 1980; Asano, 1985; CGWB, 1994). The methods may be generally classified in the following four categories (Oaksford, 1985):

(1) Direct surface recharge techniques are among the simplest and most widely applied methods (ASANO, 1985; Todd, 1980)
(2) Direct subsurface recharge techniques access deeper aquifers and require less land than the direct surface recharge methods, but are more expensive to construct and maintain (CGWB, 1994)
(3) Combination surface-subsurface methods, including subsurface drainage (collectors with wells), basins with pits, shafts, and wells can be used in conjunction with one another to meet specific recharge needs.
(4) Indirect recharge techniques include the installation of groundwater pumping facilities or infiltration galleries near hydraulically connected surface water bodies (streams or lakes) to lower groundwater levels and induce infiltration from surface water bodies (Helweg et al., 1978).
The recharge process is extremely complex, and, due to the numerous factors affecting the process, is only partly understood. The studies on artificial recharge techniques are mostly site-specific and descriptive in nature, which gives little insight into the potential success of implementing this technology in other locations.

Traditional Water Harvesting, Conservation and Recharge Systems In Tunisia

Throughout the semi-arid lands of the developing world, small scale, resource-poor farmers who manage such risk prone and marginal environments, remain largely untouched by modern agricultural technology. Although risk and uncertainty dominate the lives of these rural inhabitants, many farmers have been able to develop durable farming systems through the use of innovative soil and water management systems and the use of locally adapted crop species and varieties (Barrow, 1999). Based on ecological rationale and by manipulating nature indirectly (i.e., concentrating scarce rainwater as well as through provision of supplementary water during critical times) farmers perform small-scale management of the local environment which moderates natural vagaries allowing them to obtain a sustainable harvest from the land, even in the midst of drought.

The semi-arid region of Tunisia is one of the most populated semi-arid areas in the world. The semi-arid region of Tunisia has been periodically affected by moderate to extreme droughts, jeopardizing livelihoods and severely impacting the life standards of millions of family farmers.

Out of a total land area of 155000 km^2, non-arid area is estimated at 37,000 km^2 (24%), arid area 55,000 km^2 (35%) and desert 63,000 km^2(41%).

Over the past 30 to 35 years, Tunisia has been actively evaluating and mobilizing water resources in the country. The progressive management of water has been a central component of Tunisia's socio-economic development strategy, and investments in the water sector have made up 40-65% of the Ministry of Agriculture's budget. In Tunisia's tenth economic plan, drafted in 2002, the mobilization of water resources was reiterated. This process of water mobilization will include the implementation of a comprehensive system of large and small dams and a water supply network that allows connections between surface and groundwater reservoirs within and between basins to supply inland regional water saving techniques and subsidizing irrigation equipment.

The main water harvesting techniques encountered in the Tunisia country (Figure 2) can be subdivided into three major groups (Omrani et al.; 2008):

(i) runoff water harvesting that makes use of runoff as it is collected, thus eliminating the need for storage-included among such systems are the related micro-catchment techniques called meskat and jessour;
(ii) loodwater harvesting and spreading or spate irrigation using diversion dykes (mgoud);
(iii) runoff water collection and storage in reservoirs of variable capacities, which provides drinking water for people and animals, as well as water for irrigation purposes.

Since the works on traditional water harvesting, were published, a large number of studies have been made of the methods used to induce, collect, store and conserve local surface runoff for agriculture in arid and semi-arid regions. A compilation of these techniques was recently produced by Ennabli, 1993; Ben Mechlia et al.,2004; Ouessar et al.,2006; Ouessar, 2007.

Agriculture occupies 28% of the total land area of the country; however, it consumes approximately 80% of the water resources. Although agriculture is traditionally and predominately rainfed; irrigated agriculture has grown from 1.6% to 7% over the period between 1997-2001. Inappropriate and poorly applied surface irrigation techniques have resulted in significant water losses, and over the past few years, the government has made considerable efforts to improve the efficiency of irrigation by introducing water saving techniques and subsidizing irrigation equipment. The involvement of water users in the management of the resource has been very important in changing the social concept of water, and redefining its value in economic terms. Increased awareness of the scarcity of water and the need for its rational use has been a success of this policy.

Irrigation in Tunisia differs from most regions in the world, because the water used is high in salt concentration, approximately 4-6 times higher than standard irrigation practices. The use of brackish, low quality water has been extensively developed in the country. The most common type of irrigation practice is gravity irrigation, which accounts for 75% of all systems. Sprinkler (20%) and drip irrigation (5%) systems are not as prevalent.

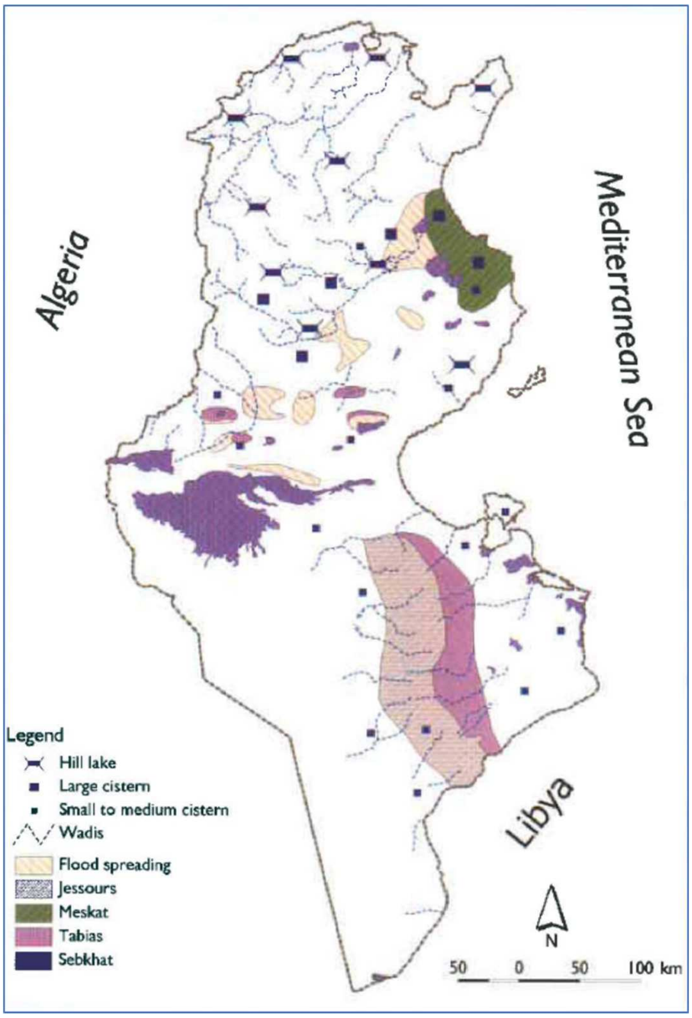

Fig. 2. Geographical distribution of traditional water harvesting, conservation and recharge techniques in Tunisia (adapted from El Amami, 1984; Ben Mechlia and Ouessar, 2004; Ouessar, 2007).

Many water harvesting techniques, which make use of runoff as it is collected, have been operational for several hundred years. These include two related major techniques of micro-catchments, locally known as Meskat in the central coastal area where the mean annual rainfall is around 300 mm, and Jessour in the more arid zones (150 mm) (Ben Mechlia et al., 2009).

A wide variety of traditional and contemporary water harvesting technologies, such as terraces, *Meskat*, *jessour, tabias*, cisterns, gabion check dams and recharge wells are used in the study area. Water harvesting in the studied watershed has a long history as evidenced. The Meskat and jessour systems are still used in southern Tunisia to support production of olives, date palms and figs (Oweis et al., 2004).

In Tunisia the area under Meskats reached a peak of about 300 000 ha during the 1970s but has declined steadily since. In the southern region of Tunisia where the annual rainfall ranges between 150 and 230 mm, the areas treated with traditional water harvesting techniques (mainly jessour: small retention dam) were limited to the upper parts of the wadi catchment zones (El Amami, 1984). However, with the independence there has been a gradual extension of the cultivated fields, mainly olive trees, to the neighboring areas thanks to the confection of tabias (same as jessour but practiced on foothills) and water spreading structures in the foothills and surrounding plains (jeffara), exploited normally as rangelands. In parallel, the soil and water conservation service of the Ministry of Agriculture has also introduced new techniques (gabion units, ground water recharge wells, etc.) especially during the last decade, which witnessed the implementation of the national soil and water conservation strategy and the water resources mobilization strategy. Then, the enrichment of the existing traditional techniques has raised the question of the nature of the linkages between the traditional and the newly introduced water harvesting techniques, are they complement or conflicting? What are the perceptions of the local communities of these changes in the landscape occupation?

Macrocatchment rainwater harvesting (Pacey and Cullis 1986; Barrow 1999) has a long history in the Matmata Plateau, dating back many hundreds of years to the original Berber inhabitants. Here, climate, topography and soils together make rainwater harvesting very effective. The majority of rain falls as high intensity-low frequency downpours. Overland flow is generated rapidly and it travels quickly over the steep slopes, supplying water and soil to valley bottoms. Earthen check dams (tabias) are sited progressively downslope to trap eroded material from the valley sides and this material is levelled to form agricultural fields (jessour). Water that is trapped behind tabias after rain events infiltrates into the soil and it can create a temporary, phreatic water supply. The rainfall multiplier effect of rainwater harvesting depends primarily on the ratio of catchment area to cropped area. On the western outskirts of Matmata, a ratio of 6:1 translates into field sizes approximating 0.6 ha and catchment sizes of around 4 ha (Hill and Woodland, 2003). Despite the existence of many techniques, some of them modern and others traditional have been used to valorize the runoff water, the most important and usable technique in Matmata Mountain is the traditional technique called "*Jessour*" and it is used basically to harvest and store water and erosion products behind their dykes (Gasmi et al.,2014).

The meskat and jessour systems are still used in southern Tunisia to support production of olives, date palms and figs. The use of water harvesting techniques is not only restricted to collecting water for agriculture. In order to increase the amount of water available for crop production and cattle breeding, several types of water harvesting techniques have been developed in Tunisia: Meskat, Jessour, Tabia, terraces, cisterns, gabions, recharge wells

Meskat is a traditional system consisting of two compartments, a catchment area and a downslope cropping area, both delineated by low bunds. Catchment and cropping area are connected by a spillway. Meskat is term used in Tunisia for an indigenous water harvesting system supporting mainly olives and figs. This system consists of catchment, or meskat, occupying the slope adjacent to a flat cultivated area called manqa. In Tunisia, the "Meskat" (Fig. 13.5 and 13.6) system has a long tradition and are also still practiced (El Amami, 1977). The "Meskat" micro-catchment system consists of a catchment area (the meskat) of about 500 m^2 and a crop ping area (Manka) of about 250 m^2. The catchment and cropping areas are surrounded by a 15–30-cm-high bund equipped with spillways to let runoff flow into the cropping plots. Meskats are suitable for areas with 200–400 mm annual rainfall and land slopes of 2–15%. A Meskat has one catchment area but may have more than one cropped area, laid out in series so that surplus runoff water spills over from one cropped area to another one. The success of the Meskat system is related to (Ben Mechlia et al., 2009):

(i) the low slopes, usually 2-10%, but never exceeding16%,
(ii) the good infiltration rate, depth (more than 1 m) and holding capacity of the soil,
(iii) the good rooting system of the grown olive trees, and
(iv) the use of the runoff area for grazing, which improves farmers' income

As for the social and institutional setting, the Meskat system has been developed mainly on private lands and embankments are designed so that all rainwater collected is kept within the farm. There is also a specific legislation that recognizes farmers' rights over runoff water. Meskat cover about 300 000 ha in the region of Sousse, representing about 5 million productive olive trees (El Amami, 1986). The typical landscape is dominated by rolling topography and soils having sandy loam textures, good infiltration rates and high water retention capacity. The method involves basically a catchment area, and a smaller collection area in which olive trees are grown. The cultivated area is formed by one or several compartments bounded by earthen embankment and connected by spillways (Ben Mechlia et al., 2009).

Jessour, Jesser, Katra (Arabic): Jessour is an Arabic term describing the widespread indigenous wall structures built across relatively steep wadis in southern Tunisia. The walls are usually high because the slope is steep. They are made of earth, stones or both, but always have a spillway, usually of stone. This system is similar to wadi-bed cultivation except that it is used on steep wadi beds and always includes a spillway to release the excessive water. Jessour is the plural of a Jessr which is the hydraulic unit comprising a dyke, spillway, terrace (cropping area: fruit trees and annuals), and impluvium (runoff catchment area) (Fig. 13.7 and 13.8). Jessour are built in the inter-mountain run-off courses and consist of a series of stone and earth walls, called tabias *(or sed, katra)*, that are erected across the stream beds of narrow valley watersheds. In Tunisia, the "Jessour" system has a long tradition and are also still practiced. Jessour is an ancient runoff water harvesting technique widely practised in the arid highlands of southern Tunisia. After each rainfall event, significant volumes of runoff water accumulate on the terrace and infiltrate into the soil to sustain trees and crops. The spillway ensures sharing the runoff water with downstream users and the safe discharge of excess water. This is an old runoff water harvesting technique widely adopted in arid highlands, which occupies the runoff watercourses. The hydraulic unit of a jessour is the jessr consisting of three components: the impluvium, the terrace and the dyke. The impluvium or the catchment area is used for collecting (harvesting) the runoff water. The terrace or the cropping zone is the area where crops or trees are grown and where the runoff water is caught. The dyke is a barrier established to block the sediments and runoff water. Its body is made of earth equipped with a central and/or lateral spillway and one or two abutments. This should assure the evacuation of excess water. A single unit is made of three components: impluvium, terrace and dyke. The impluvium is the area which collects and conveys runoff water. During heavy rainfall events, a unit can also receive water from upstream units. The terrace or cropping zone is formed by artificial soil resulting from long-term sediment deposits; in some cases, soil depth can reach 5 m. In general, fruit trees are grown on terraces (olive, palm, almond, fig), but legumes and cereals can also be planted in good years. In Jessour, the dyke acts as a barrier to hold back sediments and runoff water. Dykes are trapezoidal in shape, 15-50 m long and 2-5 m high, and are made of earth consolidated with a coating of dry stones to reduce the erosive effects of wave action of water on the front and back of the dyke. A central or lateral spillway as well as one or two abetments are used for emptying excess water. Spillways are made up of stones arranged in stairs in order to absorb kinetic energy of the overflow (Ben Mechlia et al., 2009). Dykes are built more frequently with soil from the bottom of the valley, and they armed in the downstream by a wall of dry stones to make it more powerful and we talk here about "*Sirra*". Torrential rain in the mountainous areas causes an important volume of loose of materials such as silt and sand extracted from the slope by runoff and consequently across the time accumulated behind the tabia to form the "*kliss*". In fact, to protect the dykes from destruction two types of spillway are constructed to evacuate excess water to the next units located on the downstream, the lateral spillway located in the end of dyke called "*Menfess*" whereas the "*Masraf*" is the central spillway which is much more difficult to construct, since their building requires a lot of investments in labor and materials. Every jesr has an impluvium or catchment area for which is considered as a watershed and it's naturally delimited by the water parting line between the different units (Boufaroua, 2002, Boufaroua et al., 2001; Chahbani, 1990; Gasmi et al.,2014). Jessour are generally located in hilly areas where the slope is fairly steep, usually higher than 4-5%. The jessour is the plural of a jesr which is a hydraulic unit made of three main components; the dike, the terrace and the impluvium. The rainfall multiplier effect of rainwater harvesting depends primarily on the ratio of catchment area to cropped area. On the western outskirts of Matmata, a ratio of 6:1 translates into field sizes approximating 0.6 ha and catchment sizes of around 4 ha (Hill and Woodland, 2003). In Tunisia about 400,000 ha are covered by jessour, particularly in the Matmata mountain range, where they generally occupy the runoff pathways (talwegs). This system can provide the fruit tree plantation with about 2,000 m^3 extra water during the rainy season. Whereas the "Meskats" are mainly found in the Sousse region, the "Jessour" are widespread in the South (Matmata). The "Jessour" system is a terraced wadi system with earth dikes ("tabia") which are often reinforced by dry stone walls ("sirra"). The sediments accumulating behind the dikes are used for cropping. Most "Jessour" have a lateral or central spillway. The "*Mgouds*" in Central Tunisia are channel systems used to divert floodwater from the wadi to the fields (El Amami, 1977). Like in other regions of Tunisia and the world, terraces are constructed on steep slopes using small retaining walls made of rocks to slow down the flow of water and to control erosion. It seems that this technique is the oldest adopted water harvesting technique in the watershed. The Jessour, covers about 400,000 ha of the arid mountainous area of southern Tunisia (El Amami 1984). It provides adequate control of runoff on steep slopes in areas where annual rainfall varies from 100 to 250 mm. The technique is based on the use of a large area with steep slope for runoff and the development of agricultural activities on the alluvial deposits. The water collection area consists of a series of terraces, so water can accumulate successively in several terraces as it flows downstream. Locally designed berms provide good protection of the cultivated area, prevent violent floods and ensure controlled use of the runoff water (Ben Mechlia et al., 2009). Jessour are recognized as an ancient method for collecting runoff water from the long slopes, which allowing the use of stored water for the planting of trees (olive, peach, almond…) and the practice of annual crops (wheat, barley), chiefly in Matmata Mountains (Gasmi et al.,2014).

Tabia on the piedmont area. Tree products (olive, almond, fig, palm) and annuals (barley) can be harvested. This technique tabia is a replica of the jessour system constructed in the foothill and piedmont areas. It is a relative new technique constructed by mountain dwellers. So, it is considered as a relatively new technique developed by the mountain dwellers that migrated to the neighboring plains. Alaya et al. (1993) reported that some ancient remnants of tabias were found in the region of Gafsa. However, this system has been adopted in neighbouring foothills and plains of central and south-eastern regions (Jeffara) of the country following the transformation of pasture lands to cultivated fields. The tabia collect and retain run-off water and silt washed down hillsides by rainfall, forming terraces in a stair-step fashion down the natural slope. The tabia technology is similar to the jessour system but is used in the gently-sloping foothill and piedmont areas. It is considered to be a relatively new technique, developed by mountain dwellers who migrated to the plains. Tabia, like jessour, comprise an earthen dyke (50-150 m in length, 1-2 m in height), a spillway (central and/or lateral) and an associated water harvesting area. The ratio of impluvium to cropped area in Tabia vary from 6 to 20. The ratio between the area where water is applied (cropped area) and the total area from which water is collected varies from 1:6 to 1:20. The differences between the tabia and the jessour systems are that the former contains two additional lateral bunds (up to 30 m long) and sometimes a small flood diversion dyke (mgoud). Small tabia are constructed manually using shovels, pickles and carts. Larger constructions are done mechanically using tractors and bulldozers. Tabia have a central or lateral spillway and two additional lateral bunds. Fruit trees and annual crops are commonly grown.

A Tabia collects, on a cultivated area of 5% of the catchment, eight times the amount of each rainfall storm above 20 mm. Tabia are also an effective means to control soil erosion and improve groundwater recharge. Tabia are found in piedmonts and plains in areas with slopes under 3%. Tabia is formed by an earth bund, reinforced from below by a stone wall, on the sides by a stone-lined spillway typically erected along contour lines, and at the ends by lateral bunds. Water is stored until it reaches a height of 20 to 30 cm and is then diverted, either through a spillway or at the upper ends of the lateral bunds. The tabia gains its water directly from its water storage basin (*impluvium*) or through diversion of *Wadi* run-off. The tabia are now widely used in the piedmont areas where the fruit trees (mainly olive and almond) groves are gaining large areas at the expense of grazing lands. The gabioning technique has been very attractive and hundreds of units are installed on the main wadi courses as small check dams or spreading structures for diverting runoff waters. he tabias and jessours in Tunisia are a good example of floodwater harvesting within a streambed in a region with 100–200 mm rainfall. The meskat and mankaa also in Tunisia are examples of water harvesting systems using a long slope in regions with 200–400 mm rainfall. The tabia is a runoff water harvesting techniques widely practised in central Tunisia. Tabias are usually installed on the piedmont areas where the slope does not exceed 3 % with relatively deep soils. It has the same components as jessours: a dyke (50-150 m length, 1-1.5 m height), a spillway (central and/or lateral) and an impluvium. The impluvium/cropped area ratios vary from 6 to 20. The differences between the tabias and jessour are the two additional lateral bunds (up to 30 m long) and sometimes a small flood diversion dyke (mgoud) (Alaya et al., 1993). Fruit trees and annual crops are commonly grown. This system has been adopted in neighbouring foothills and plains of south eastern regions (Jeffara) following the transformation of pasture lands to cultivated fields. Besides their water harvesting qualities, tabias have also positive effects on soil erosion control and on groundwater recharge.

Cisterns, locally known as *fesquia* or *majel*, are built to collect and store rainfall. Cisterns are subsurface water reservoirs / storage tanks (Fig. 13.10). Cisterns can be traced back to before 3000 BC –and even earlier, when natural caves were used to store water long before man-made cisterns (Wahlin, 1997). The first cistern was dug in the Middle and Late Bronze Age, about 2200 to 1200 BC. The rainwater that was collected in them during the short rainy season would be enough for at least one dry season. Ennabli (1993) claimed that this technique has been used during the pre-Roman and Roman eras for the collection and distribution of spring waters. Carthage received its drinking water from the Djebel Zaghouan via an aqueduct of 50 km, collected in a cistern of 50,000 m^3. The same procedure was also applied in other big towns such as Kef, Sbeitla, Tebourba, and Sousse. The collection of rainfall water accelerated with the arrival of the Arabs. More than 200 big cisterns are found in the central region of the country. The most famous one is that of Aghlabit in Kairouan, which was built in the nineteenth century, with a total capacity of 58,000 m^3. The use of cisterns also contributed to the development of large-scale livestock husbandry in areas where groundwater is not available because of quantity or quality constraints. It was estimated that 10 to 16 million m^3 per year could be mobilised by this type of hydraulic infrastructure (Ennabli, 1993). While studying a micro-catchment in the region of Beni Khedache, found that the cistern water is not fully exploited. Through a cost benefit analysis simulation, they showed that the stored water in cisterns has a high potential for improving the farming system and incomes of jessour-based agriculture by practising supplemental irrigation and/or small-scale full irrigation speculations under green houses (Sghaier et al., 2001). In the rangelands of Dahar, selling of cistern water is a widespread and attractive practice, especially during summer periods. Cisterns were traditionally used to provide drinking water. Runoff water is collected and stored in stone-faced underground small or large size cisterns, called majel and fesquia. It is estimated by Ennabli (1993) that a tank of 35 m^3 capacity can meet the annual water needs of a family and its livestock. Small private or communal cisterns (5 to 200 m^3) and big cisterns (up to 70,000 m^3) are found throughout the water deficient zone under the 400 mm isohyet. There are numerous old and new cisterns in Tunisia. The water is used for different purposes including domestic consumption, irrigation and for livestock. Cisterns are indigenous, subsurface reservoirs with a capacity ranging from 10 to 1,000 m^3. Many small and big, private and communal cisterns, mainly built during the Roman and Arab-Muslim eras, can be found throughout the arid zones of Tunisia. They increase the availability of water for multipurpose use (drinking, animal consumption, supplementary irrigation) in remote areas. A cost-benefit analysis showed that the stored water has high potential for improving the farming system and incomes of jessour-based agriculture (Ouessar in Taamallah et al., 2010). A cistern is a whole dug in the soil with a gypsic or cement coating to avoid vertical and lateral infiltration. Generally, each unit is made of three main components, the impluvium, the decantation basin, and the storage and pumping reservoir (Ouessar et al.,2002). In many areas small cisterns are dug in the rock. Larger cisterns are lined with compacted earth, clay, mortar coating, concrete or plastic sheets to avoid seepage. Runoff is collected from an adjacent catchment or channeled from a distant catchment. Problems include the cost of construction, limited capacity, sediments, and sources of pollutants from the catchment.

Basically, a cistern is a hole dug in the ground with gypsum or concrete coating to avoid vertical and lateral infiltration. Each unit is made of three main parts, the impluvium, the sediment settlement basin, and the storage reservoir. The impluvium is a sloping piece of land delimited by a diversion channel (*hammala*). In the flat areas, where it is possible also to exploit the floods via a diversion dyke, one also finds artificially paved runoff areas. A small basin before the entrance of the cistern allows the sedimentation of runoff loads. It improves the stored water quality and contributes to the reduction of maintenance costs. Big cisterns have, in addition to the storage compartment, a pumping reservoir from which water is drawn. A cistern is a sub-surface water collection and storage structure, generally dug at the lowest level of a small catchment. To be effective, a cistern should have an adequate catchment to generate runoff under whatever rainfall conditions are expected, a suitable underlying geological formation, and should make efficient use of stored water. The first runoff from the catchment is usually diverted away; only the subsequent (cleaner) flow is allowed to enter the cistern. A ditch disposes of the surplus water at downstream through an outlet. The water from the cistern is extracted manually by bucket or hand pump (Ali et al., 2009)

Terraces or contour benches: Contour-bench terraces are constructed on very step slopes to combine soil and water conversation with water harvesting techniques. The terraces are usually provided with the drains to release excess water safely. The historic bench terraces in Tunisia are good example of this system. The terraces are used for cultivation of fruit trees (olive, fig, almond, date palm, etc.), legumes (pea, chickpea, lentil, broad bean, etc.) and cereals (barley, wheat). It is practiced in the inter mountain and hill water courses to intercept runoff and sediments. The contour benches are earth embankments built along contour lines, perpendicular to the slope, to intercept and store runoff water. They improve infiltration locally. The benches also reduce both the length of slope susceptible to runoff and the runoff velocity, which remains below the critical threshold of gully erosion. They are increasingly built with earthmoving machines and are referred to as machine-made benches. There are two types of erosion control benches: total retention benches and diversion benches, the former being the most common. In Tunisia, these structures have been considered to be effective in regions where rainfall is rare, brief and very intense, falling on dry soil with low permeability. (Nahal, 1975). Contour bench terraces are constructed on land with steep slopes of 20–50%. This technique combines soil and water conservation with water harvesting. Cropped terraces are usually built to be level, and supported by stonewalls to slow down runoff and control erosion. Terraces may be used in areas where the annual rainfall is between 200 and 600 mm. The construction can be done manually or using heavy machines. Construction costs and labor requirements for maintenance are high. If catchment surfaces are left bare, erosion may become a problem. On milder slopes of 10% or less with deeper soils, conservation bench terraces might be the best technique among the contour terrace types. Unlike contour bench terraces, there are no supporting stone walls constructed due to lower land slope (Oweis et al., 2012)

Gabion check dam : These units are made of wire mesh cages filled with rock, and are constructed in wadi beds in order to divert water directly to the neighboring fields, often located within the wadi itself. These structures are made of blocks of galvanized nets (gabion) filled with rocks. They are built in the *wadi* beds. In general, they have the form of a rectangular spillway. The technology of check dam is a technique consisting of binding different gabion cages filled with small stones together to form a complete flexible gabion unit. In order to slow down the water flow in the wadi courses and improve its infiltration into deeper soil layers and geologic formations, small check dams are installed on the wadi beds. They are usually positioned in series, with a spacing of 100-500m. These dams are made of gabion. The gabion technique has been first introduced in the civil engineering domain. They are largely used since then and found many applications. A gabion is a cage which has a cubic shape filled with stony material of suitable diameter enclosed in metal grating keeping the stones together and stops them from moving under the pressure of water. The gabion is normally the name of the cage only but it is also used frequently for the whole structure itself. The technique of gabion check dam consists in binding different cages together to form a complete gabion unit. The average height varies from 1 to 4 m and its length is a function of the width of the wadi bed (Royet, 1992).

Recharge: Water harvesting is practiced in many ways to solve the various water needs of people living in the dry areas. Some of the techniques are used solely to provide water for plant production, while the others are used to provide water for human and animal consumption or for groundwater recharge. *Recharge wells* are casting tubes drilled into the underlying bedrock – when of very low permeability – enhancing the infiltration of runoff water to the ground water table. This technique was adopted only recently in Southeastern Tunisia. When the permeability of the underlying bedrock is judged to be very low, casting tubes, known also as recharge wells, could be drilled in to enhance the infiltration of runoff water to the aquifer. *Artificial aquifer* is replenished each year and water will be available in the sandy aquifer during the dry season (Hoogmoed, 2007; Borst et al., 2006; Quilis et al.,2012). In Tunisia artificial recharge has been used effectively for the storage of harvested flood water. Tunisia has experience in the artificial recharge of aquifers since early 1956 (Cary et al., 2012; Gaaloul et al., 2017; Gaaloul et al., 2014; Sales et al., 2017). Currently, there exist more than 64 recharge zones of 23 aquifers. Since 1958, Tunisia has started the artificial recharge technique. Generally, surface water is used in artificial recharge, by dam's lake and underground dam infiltration, crossing the riverbed infiltration, injection wells, or infiltration basins. Several experiments of recharge by surface water were established, especially in the Teboulba aquifer from 1970. Artificial recharge of the Grombalia aquifer was set during the 1975–1978 period at Oued Sidi Said station by three infiltration basins. From 1988, artificial recharge of the Kairouan aquifer is done by infiltration in riverbed from the El Houereb and Sidi Saad dams. In Menzel Bouzelfa region, artificial recharge was performed by injection of surface water in three wells since 1990. In 1986, the ground water artificial recharge by treated wastewater at the experimental station in Nabeul Oued Souhil (Irrigation efficiency) is the first pilot project in this field. Besides reclaimed water reuse for agricultural purposes, seasonal recharge of the shallow and sandy aquifer of Nabeul Oued Souhil has been performed since 1985. In 2008, a new pilot site was established in the region of Korba-Mida (Recharge aquifer and seawater intrusion) to recharge the aquifer with domestic treated wastewater of the Korba (Gaaloul et al., 2012; 2013; 2015). The aim was a better evaluation of the mixing processes between seawater, groundwater bodies and the new recharge contributor, and of the changes due to intense groundwater withdrawal, which will be useful from a water resource management perspective aimed at controlling human interference on the Korba plain groundwater. Korba aquifer (northeast Tunisia) is one of typical example of coastal aquifer in semi-arid regions that have been intensively overused during the last years.

CONCLUSION

Tunisia is a marginal country hydrologically and it has adopted a number of distinctive of traditional water management for agriculture. Tunisia contains three different climate zones: Mediterranean, semi-arid and arid, which experience differing water availability. Due largely to these differences in potential water resources, there exist a number of distinctive methods of water management for agriculture. Water resources in Tunisia are characterized by scarcity and a pronounced irregularity. Tunisia has been able to develop a complex and diverse water infrastructure allowing the country to mobilize and exploit available water resources. The various installation hydraulics through the history be the old man stopping in stone allot with Roman (it be the case in the oasis of Gabes) and the system of harvest of rainwater in Kairouan. In the south of Tunisia, the inhabitants built a fortress (ksar) on the most inaccessible site in the area, and used it to store the local population's food reserves. The fortress was protected by outlying posts and an early alarm system. At the same time, the town's residents developed water harvesting techniques (earthern dikes or jessour, and cisterns) for the mobilization and use of rainfall and runoff waters. These water harvesting systems are still in use today.

The jessour, built in the intermountain runoff courses, capture water and silt and create terraces where fruit trees and annual crops are cultivated. The cisterns, locally known as majen or fasquia, are small to medium (1 to 50 m3) subsurface reservoirs where rainfall and runoff are stored for domestic uses, livestock watering and occasional supplemental irrigation. The water-harvesting techniques are well adapted to the physical and social environment in which they are used. These techniques have various functions, such as water supplemenration, flood prevention, water table recharge and water and wind erosion control. Water Harvesting, conservation and recharge, defined as the collection of runoff and its use for the irrigation of crops, pastures and trees, and for livestock consumption. The common goal of all forms is to secure water supply for annual crops, pastures, trees and animals in dry areas.

In the past, water harvesting was the backbone of agriculture in arid and semi-arid areas world-wide. After a decline, it gained new interest during past decades. Its future role will be as a linking element between rainfed agriculture, soil and water conservation and irrigated agriculture, still using untapped water resources in arid lands, alleviating slightly the stress on drought-ridden farmers and communities. Surface storage of water is unfeasible so communities practice traditional rainwater harvesting within small hillside catchments or oasis irrigation using artesian water. The dry areas on Tunisia very rich in traditional, ancient water-harvesting systems. These must have been built on a sound foundation of indigenous knowledge. Such traditional knowledge should be utilized in order to develop new practices, or to improve the efficiency of existing ones. Tunisia is a marginal country hydrologically and it has adopted a number of distinctive methods of water management for agriculture. The central region supports modern dam irrigation, whilst traditional rainwater harvesting is practiced in the south. Analysis indicates that traditional water management advantageously partitions the continuum dividing hazards and resources through subtle manipulation of the environment.

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