Desalination and Water Treatment
www.deswater.com
doi: 10.1080/19443994.2013.807082

52 (2014) 2841–2849
March

Taylor & Francis
Taylor & Francis Group

Management of water resources in the oasis of Figuig, Morocco

M. Salgot[a,*], A. Torrens[a], P. Casanova[b], E. Queralt[b], O. Elhachemi[c], H. Elhalouani[c], C. González[d]

[a]*Soil Science Laboratory, Faculty of Pharmacy, University of Barcelona, Avda. Joan XXIII s/n 08028, Barcelona, Spain*
Email: salgot@ub.edu
[b]*Comunitat d'Usuaris d'Aigües del Delta del Llobregat, Avda. Verge de Montserrat 133, 1, 2, 08820, El Prat de Llobregat, Spain*
[c]*Laboratory of Water, Faculty of Sciences, Environment and Ecology Sciences, University Mohamed I Oujda, Av. Mohamed VI, Oujda 60000, Morocco*
[d]*Fundació Món-3, Faculty of Economics, University of Barcelona, Avda. Diagonal 690, 08034 Barcelona, Spain*

Received 18 October 2011; Accepted 20 March 2013

ABSTRACT

Oasis and the small town of Figuig are located in the far south-east at the Oriental region of Morocco near the Algerian border. In this desert area, water resources are limited and collective sanitation is not fully applied. Water used is obtained from wells, scarce and temporary surface sources and mines (*foggaras*). The main irrigation technique is border irrigation, but drip systems are also being introduced. A dam is being built at some distance from the village and the possibility of reusing treated wastewater after the implementation of wastewater treatment plants (WWTPs) is being considered. Over the last years, cultivated land increased due to new wells mainly built without any control. This situation has lead to an overexploitation of the aquifer and soil salinisation. Only one neighbourhood has a complete sanitation system with sewerage and a WWTP using a series of stabilisation ponds (WSP) built in 1998 with the aim of treating the wastewater and subsequently reuse it for agricultural irrigation purposes. Món-3 NGO, teams from the University of Barcelona (UB) and CUADLL have been collaborating with the municipality for the implementation of a sustainable water management project focused on water resources, but the need to cope with the rest of the components of the SPAC (Soil-Plant-Atmosphere Continuum) arose. Measures to counteract water salinisation and soil losses are needed, but still difficult to implement.

Keywords: Water resources; Sanitation; Oasis; Figuig; Morocco

1. Introduction

Desert areas experience a structural and permanent water shortage, which implies that available water has to be carefully managed. Human settlements in the deserts are usually located in the oases; the result of careful water management by humans through centuries, which can make small areas of deserts fertile. The new approaches to environment

*Corresponding author.

Presented at Water and Environment International Conference (WATEIC 2011)
Marrakech Morocco, 26–29 October 2011

management based on the intensive use of energy and machinery are compromising the equilibrium which lasted for centuries. A consequent land degradation and biological impoverishment intensify within an ever increasing aridity cycle [1].

Among the desert systems management, there are several measures to manage oases' water resources, from the technological ones (transportation from water-rich areas, desalination) to the more ecological (reclamation and reuse of wastewater, runoff use and deficit irrigation practices). In all cases, it seems evident that integrated water management is paramount in the desert, especially if there is agricultural use of the resource.

Of course, aridity is the major constraint in the oases. The traditional water exploitation techniques, such as derivation dams, khettaras (foggaras, qanats), wells and cisterns, formerly were used to cover the main needs of population and crops, but now tend to be discarded [2]. Other traditional practices, like microcatchments around the trees or dryland farming, are also abandoned. It seems, then, that at present, a compromise should be reached trying to maintain the still useful old techniques and the scarcity of cheap labour available, while also using new technologies when adequate.

Figuig, north-eastern Morocco, located at the juncture of the High Plateaus and the north-western edge of Sahara is an oasis town surrounded on three sides by the Algerian border (Fig. 1). Figuig consists of seven ksars (walled villages) and lies in the basin of the Wadi Zousfana that is nearly 900 m above sea level [3]. The town was established more than 1,000 years ago and has survived due to a vital supply of water from local springs and a small branch of the Ziz River, Zousfana, which passes along the edge of the oasis (Fig. 2). A stopping point on the caravan routes between Tlemcen and Timbuktu, the oasis had a stable economy that thrived on trade with merchants en route and a productive agricultural base [4]. Figuig is a typical oasis, a green spot surrounded by barren land. Nevertheless, the reality is far more complex. Soil, water, plants, wind and water-driven erosion and farmers create a unique environment which necessarily should reach a steady-state or the equilibrium will be broken and the entire oasis will be compromised.

The closing of the border with Algeria more than 20 years ago caused one of the masterpieces of the economy of the town to disappear as almost all the agricultural land remained in the Algerian part of the border, but in the Moroccan side, semi-arid grazing land—used by sheep and goats—and a small part of the palm trees remained. The local industry includes the fashioning of pottery, the tanning of skins, the manufacturing of leather goods and the weaving of fabrics.

Meszoely [4] indicates that Figuig had 26,000 inhabitants but at present this number seems to be reduced; to 12,000 [5], quoting the 2004 Moroccan census or 15,000 [6]. The oasis is divided into two levels. Upper Figuig is situated 900 m above sea level and Lower Figuig at 870 m. The community used to be organised in seven separate groups (depending on the initial origin of the inhabitants) called ksars. The majority of ksars—six—are in the upper part, while the most important—Zénaga—is located in the lower reaches of the site [7].

The surface of the oasis has been mapped and evaluated as being around 900 ha, divided into 4,500 individual plots with an average area of 0.11 ha each, usually surrounded by 2 m high stone walls and openings of less than 2 m wide [8].

In this paper, a description of the present circumstances of the oasis and several options for the management of water are presented. It is to note that, from the social point of view, there is a real confrontation among the traditional and the new ways to manage water resources.

2. Water management

Almost all the studies related to water in the Figuig oasis just devote a paragraph to the water supply for people, with the studies being centred in the water used for agricultural purposes.

The traditional water management in the oasis, like in many others at that time, disappeared due political reasons in the middle of the twentieth century and this had led to degradation of the water quality and reduction of the water available.

Each ksar of the town used to have its own governance institutions and separate farmlands. The seven ksars which eventually evolved throughout the years continue to characterise the city today. The interplay of social, economic and political structures sustained a relatively stable community for generations. The critical importance of water in the survival of Figuig placed water institutions at the forefront of city's governance structure. Several of the indicated reasons are locating Figuig at present with an unprecedented water crisis in the history of the oasis [4]. Part of the water crisis can be attributed to social features because when the emigrants return home, they bring with them a different culture of water use.

Usually, the "Office National de l'Eau Potable" is taking care of water management in the towns of the

Fig. 1. Map of Figuig location.

kingdom, but in Figuig, the municipality is still managing the entire water cycle.

Corsale [2] classifies the Figuig oasis indicating that water shortage has been the main problem of similar oases, those spring-fed, characterised by the importance of groundwater and often small dimensions and tend to heavily suffer from the drying up of water resources caused by their uncontrolled exploitation.

From the indicated features, it seems important to identify present and potential water sources in the oasis.

The water resources intensively exploited at Figuig correspond quite exclusively with groundwater. Figuig.net [7] establishes that this groundwater appears at sources or is drained by the foggaras regularly operated and maintained. This exploitation is around 200 L/s, although there is a possible yearly variation as indicated by Mohammi [8] varying from 150 to 300 L/s up to 500 L/s. Nevertheless, the correct figure seems to be 200 L/s, approximately. Zousfana.com [9] indicates that some underground sources are not used because of their border situation with Algeria.

2.1. Groundwater

Torrens et al. [6] describe that the community of Figuig has two aquifers: a superficial one and a deep one. Most of the water from the shallow aquifer is intended for agricultural use, while the water from the deep aquifer is mainly used to supply drinking water to the population. At Zousfana.com [9], it is established that the true important sources of water of Figuig are artesian and exploited by the foggara technique, of which about 30–35 as indicated by Meszoely [4] are described in the area [10].

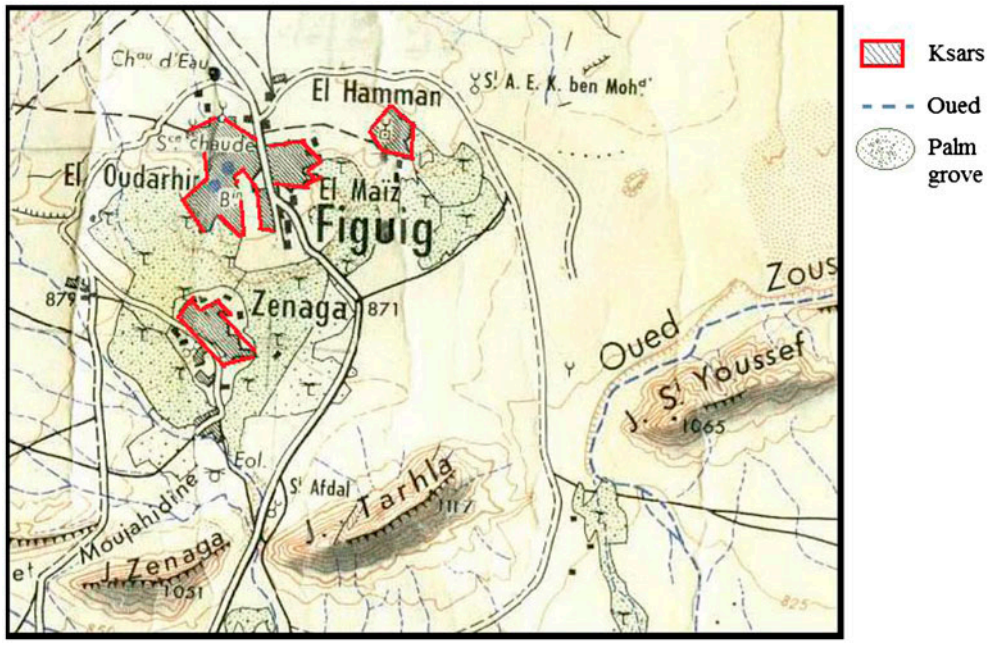

Fig. 2. Map of Figuig with the location of ksars and oueds.

A complete description of groundwater characteristics can also be found in Torrens et al. [6]. It is to note that this study is based on the geological characterisation made by Bencheriffa and Popp [11]. The shallow aquifer presents four hydro-chemical families (calcium bicarbonate, sodium chloride influenced by upwelling water, sodium chloride from irrigation water infiltration and intermediate waters), while three families are found in the deep aquifer (calcium bicarbonate, bicarbonate–calcium sulphate and sodium chloride). The high contents of nitrates found in some samples of groundwater are linked to intensive agriculture (small plots with high density of plants) and to the presence of farms near wells and water sources in the upper aquifer. The northern areas of the oasis have water of higher quality for agricultural purposes, while the ones in the south have poor quality for irrigation.

The most important source is Ain Tzadert, in relation with the amount of water delivered, but also because it used to be the cause of a number of wars and combats. The plain of Baghdad and the south-western part of Figuig hold a sub-surface aquifer exploited by pumping, but the water is saline [9].

2.2. Runoff

The water from the occasional heavy rains is mostly wasted and does not feed the aquifer of the oasis, causing floods and important damages in the village [6]. A storm water management system in the surrounding area of the basin, regulating particularly erosion, runoff and overflows is necessary to avoid floods, to improve the quality of the groundwater (less salinity) and the quantity of water available.

The *grand oued* (great wadi) "Igzher Amekrane", which crosses the gardens of the southwest of Zénaga creates problems making the borders unstable and inundating the fields [7]. Also, some neighbouring mountains, several hundred meters high in relation with the oasis altitude, can create runoff-related problems during heavy rains.

Runoff management in the surrounding areas appears as necessary to control and reduce soil erosion due to water and wind. Nevertheless, it is to consider that soils are formed by alluvial sediments. Figuig.net [7] also indicates that runoff sometimes causes devastations, especially in the Algerian part of the border.

2.3. Water supply in town

All the inhabitants of Figuig have access to potable water since the seventies [7]. The water consumption is around 40 L/hab d. No data on the amount of water per inhabitant served has been found. The calculations made using the amount of water treated by the wastewater treatment plant (WWTP) suggest a figure of around 50 L/d of water used (50–70 m^3/d produced by the WWTP (1,200 hab) > 50 L/hab d).

The town ksars were built in the location of the sources for easiness of supply and for political reasons being the foggara an equipment of the ksar. Several of the galleries of the foggaras made possible to build public baths (Hammam) and washing places. The number of Hammams is 5 [12].

2.4. Wastewater and reclaimed water

The majority of houses have been for a long time using septic tanks to manage wastewater. Nevertheless, in 1997, a project was implemented for building the sewerage system of one of the ksars, Hammam Foukhani, where collected water reaches a lagooning system. In 2004–2005, a sewerage system in the ksars, Ouled Slimane, El Maiz and part of Zenaga, was built but is not in use till date because the corresponding WWTP was not built. Cooperation with the Département de Seine-Saint-Dennis and other French organisations supported these works [13]. In 2010, a discussion with the leaders of the municipality indicated doubts about the possible location of the WWTP. The arguments were the vicinity to the town and the need to pump wastewater by one side and by the other, the reuse possibilities.

Given the characteristics of the town, one of the problems arising is the centralisation of the treatment and consequently the availability of reclaimed water vs. the decentralisation and the availability in different areas. This is, in some way, a political issue due to the relationship between several ksars. The WWTP has been suffering from a lack of technical counsels, since it was managed directly by the users in a volunteer way. With minor technical improvements, a good operation and management and minor changes, the quality of the effluent can improve dramatically. In any case, at present, the treated wastewater is mainly lost through infiltration in a sandy area near the station. This implies that at present, reclaimed water is not a resource.

In Table 1, the average results are indicated for the water reaching the ksar Hammam Foukani WWTP and the treated wastewater.

Some data could be found on the quality of tap water collected from a groundwater aquifer using a well 150 m deep. The conductivity ranges from 0.49 to 3.00 dS/m, the average contents of carbonates, sulphates and chlorides are, respectively, 263.5; 79.7 and 645.2 mg/L and for the cations, 7135.5; 7.7 and 194.9 mg/L of calcium, magnesium and sodium [14].

In order to cope with the possibility of wastewater reuse, a study [6] was undertaken by a team from Barcelona (Spain). The Hammam Foukani WWTP (Fig. 3) consists of two facultative lagoons in series, a maturation pond and a small reservoir afterwards. The population served is around 1,200 Person Equivalent and the average flow is between 50 and 70 m^3/d. The average loading is of 142 kg BOD_5/d. The main relevant characteristics of the effluent for possible reuse are EC 3.4 dS/m; suspended solids (SS) 151 mg/L; BOD_5 225 mg/L and faecal coliforms 4.4 ULog/100 mL. Helminth eggs were not found in the effluent.

Table 1
Water quality in the inlet and the outlet of the ksar Hammam Foukani's WWTP

	Influent	Effluent
pH	7.5	8
DO (mg/L)	0.4	6.0
EC (dS/m)	3.03	3.40
BOD_5 (mg/L)	372	142
SS (mg/L)	534	220
FC (ULog/100 mL)	7.5	4.4
Helminth eggs/L	35	0

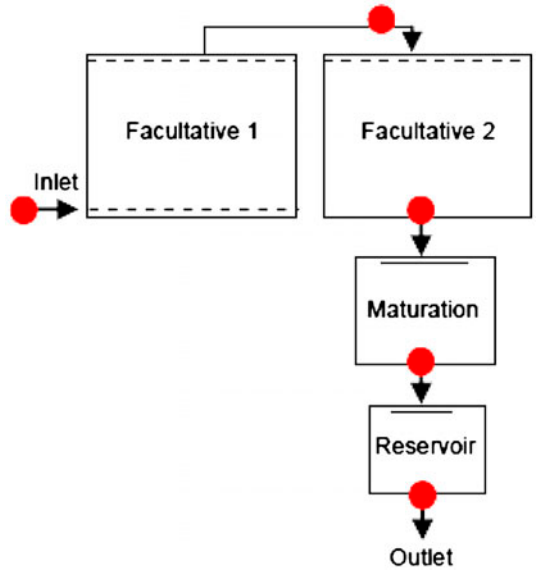

Fig. 3. Scheme of the WWTP serving the Hammam Foukani ksar in Figuig.

Nevertheless, it is to note that effluent BOD_5 can be attributed to the huge amount of algae detected, and a better configuration of the system with the reservoir and not merely as an additional pond would improve the characteristics. The maturation pond is not acting as happens with a usual design. Then, a real maturation pond or any additional facility is needed to further reduce faecal coliforms content and SS.

Apart from this, the WWTP is located facing the dominant winds which make fine sand accumulate in the perimeter of the station and enter the ponds, thus diminishing the treatment capacity. This sand appurtenance is at present managed by a tree plantation surrounding the station [6].

2.5. Irrigation water

Many studies focus on the agricultural water management in the oasis. Several authors [4,7,9] are describing the special characteristics of the classical water management in Figuig oasis, based in a collective management, especially for the distribution, of the resource. Nevertheless, as explained, this type of management is under pressure due to technological and social changes experienced by the oasis in the last 40 years and new features that appear in relation with water management.

Two main water resources are exploited at present. The sources drained by the foggaras technique and the water exploited by the use of wells in the southwestern part of the Figuig plain of Baghdad, which is saline. Surface waters are exploited in a sporadic way (when present in the Wadis Zousfana and Tfilia).

Water is distributed by open canals called seguia (plural souagui). In Figuig, almost all the souagui are concrete built, but a few ones are dug in the ground. The last ones lose certain quantities of water which allow the growth of a number of palms and other trees.

In a technical visit of part of the authors in 2010, it was observed that several improvements must be made in order to save water. Among these: reduce evaporation and water losses in the open channels and reservoirs; real metering of served flows; real knowledge of used technologies, especially drip irrigation; and use of runoff can be addressed.

3. Water quality

As indicated, the water quality in the oases suffers usually from salinity problems. Figuig waters are not an exception, and in this case, the situation is aggravated by the mentioned changes in management in the last years, creating an overexploitation of the existing resources. Then, determination of water quality is paramount for the management of the system.

As it is indicated by several authors (e.g. [15]), there are changes in the management of the agriculture, modernised and mainly intensified, in quite all oases. The agricultural intensification can be classified in vertical and horizontal, that might take place simultaneously. The "vertical" intensification, implying increasing motor pumping in traditional oases, while the "horizontal" intensification is performed through new agricultural extensions in the desert, solely based on motor pumping. Changes in animal husbandry can also be described.

The creation of new water-related infrastructures leads to the presence of several reservoirs in different places in town apart from the privately owned. Those reservoirs are open and consequently certain amounts of water can evaporate.

The present system of water management in the oasis can be described as not efficient in part, due to the following features [6,12]:

- Foggaras are designed as having water with continuous flow.
- The drainage using foggaras and pumping are overexploiting the aquifer, which with the present conditions is being slowly recharged.
- The management is not considering the actual climatic conditions.

The entire system is suffering from a salinisation increase due to overexploitation and the water extracted from the saline aquifer [12]. Only the palm trees can support the salinity of the water sources.

4. Soil

The usually less studied part of any ecosystem is its soils; nevertheless, a good study on Figuig soils was undertaken by [8]. A few references on the soils of the oasis area can also be found in the official web "ville Figuig info" [12].

The conditions existing in the area are not, and have not, been completely favourable to the soil formation activity, leading to the presence of soils not fully evolved. The cultivated soils in the area have been formed by alluvial materials which have been modified by agricultural practices, basically continuous recycling of organic manure (including the human one). The palm date soils are at present impoverished and suffer from an empiric use of fertilisers in absence of scientific support.

Mohammi [8] concludes that the soils of the oasis to be considered are of three types:

- mineral,
- scarcely developed and
- with sodic characteristics.

The first ones, mineral, have been formed over hard rocks and under an aridic climate. As a consequence,

are scarcely developed and do not have any economic interest.

The soils scarcely developed are formed over soft parent material, salinised partly by the irrigation water and are not managed well by the farmers. These soils are the only ones capable of being used for agricultural purposes.

The sodic soils are related to old lake sediments, which constitute parent material and are heavily salinised.

The study of Mohammi [8] deals also with several aspects of the erosion in the area. For example, there is regressive water-generated erosion caused in the left side of the Chaâba Tazougarte which transformed the soils into badlands, unable to be exploited. This is evident, as seen by part of the authors, near the Algerian border, besides the road which used to relay both countries and in other sites surrounding the oasis.

In general, the lack of vegetal cover is allowing a selective erosion of the finest materials of the soil, which are transported far away from the area, mainly to the Algerian part of the oasis by the occasional flows of the wadis. Then, fertility is reduced.

Aeolian erosion is also remarkable and acts by deflation and accumulation. The fine elements on surface are removed by the wind and are accumulated in several places of the oasis (e.g. near the WWTP as indicated). The result is the same, soils less fertile.

5. Agriculture

Figuig used to be an oasis of 150,000 palm trees with approximately 26,000 inhabitants until the seventies of the twentieth century [4,6].

Agriculture is central to the social and political identity of Figuig, but it needs to be related to the changing patterns of oases economy, which indicates a shift from subsistence agriculture to more commercial one. As de Haas [15] indicates, "subsistence agriculture has lost its former imperative of self-sufficiency". The changes can partially be attributed to the same general economic process of more general market integration and income diversification for most oases. Technical innovations, in particular mechanised pumping have changed the conditions under which oasis agriculture is possible. As peasants are released from the obligation to be agriculturally self-sufficient, they now have a freer choice to specialise in certain products. There are tendencies to specialise on crops relatively well adapted to local production factors as well as on a smaller number of crops as indicated afterwards, and growing number of peasants is partially producing for regional, national or even international markets.

At present, the town's date palms are not commercially important because of diseases and the high elevation of the oasis and it is evident that part of the trees disappeared. Fruits and vegetables are grown mostly for local consumption [3].

Berkat and Tazi [16] establish a specificity of the oases of the Saharan zones, including Figuig, with characteristics including highly productive irrigated agriculture on small units and a sheep breed, which is very prolific, kept in small herds and penned almost all time and a feeding calendar, where lucerne is the most important element. The feeding calendar, according to the same authors, depends on the growth of the lucerne: cut-and-carry lucerne during March–October, with other contributing sources including straw, barley, chaff and date by-products. Lucerne hay, in addition to straw and concentrates, is used from November to February.

6. Discussion

Considering the socioeconomic characteristics of the populated area in the town, the existing studies examined and the field trips of the authors, water related issues are:

- The costs related to urban water supply and sanitation must be acceptable, although the recovery of costs is to be considered. In other words, the technologies to be implemented should be low-cost in terms of energy. This reduced use of energy should be considered in terms of water pumping and transportation.
- The technologies that should be implemented for wastewater treatment must be extensive (consuming land but not energy) and adapted to the site characteristics (sunlight, temperatures, etc.).
- When observing the irrigation practices, it seems necessary to improve the study of the adequacy of the irrigation techniques and water resources management considering the desert characteristics. Drip or border irrigation, open canal transportation, pumping control, allocation of waters without considering the quality are the practices to be studied and implemented or avoided in a case by case basis.
- With these characteristics, wastewater cannot be fully used for irrigation, i.e. for every use, taking as a basis, the recommendations issued by the WHO [17].

In relation with the soil and agriculture

- Soils are a basic asset in the area and should be carefully maintained. Water and wind erosion

should be controlled by diverse means including continuous vegetation implementation, special protection by employing vegetal barriers and other sustainable techniques.
- As far as Figuig increases the availability of good quality water, the agriculture will also improve.

Nevertheless, there is a need to perform basic studies, at least defining:

- The vulnerability of the different groundwater areas of the oasis.
- The salinity of water resources.
- The capacity of soils for accepting reclaimed water.
- The hazards and risks associated to wastewater reclamation and reuse, especially with respect to water-related illnesses.
- The plants that could be grown considering the quality of all the water resources available.
- The possible diversification of crops apart from the palm trees.

Managed Aquifer Recharge as defined by Dillon et al. [18] could allow, if applied, a better management of the entire water resources of the oasis. In fact, a management tool is absolutely necessary to define water availability in the entire oasis area, especially if new agricultural land is to be exploited.

7. Concluding remarks

There are several solutions to reduce the structural water deficit in Figuig and the surrounding area according to the previous works considered and the present experiences. Among them, the authors are wishing to indicate that:

(a) In short-term, there are several urgent actions to be implemented:

- Runoff is one of the potential resources which must be managed by operating in the entire area, not only in the vicinity of the village. At the same time, the control of the flooding waters will help to maintain the soil resources absolutely necessary for the improvement of agricultural practices and the self-sustainability of the town in terms of food. Runoff control allowing greater water retention times in the area will improve water availability as well as its quality.
- Water management should be based on the control of the demand instead of implementing an indiscriminate increase of the offer.
- The analytical control of the entire water cycle in the oasis is paramount. The new laboratories implemented in the municipality could exert a basic and essential role in the Figuig context.
- There is a need to recover several old agricultural practices nearly forgotten, e.g. rain farming or microcatchments. Remnants of these practices can still be detected in the area.

(b) Medium-term actions can be described as follows:

- It is necessary to implement a project for the integrated management of all the water resources in the area before deciding on the technologies and structures devoted to the potential use of nonconventional resources.
- Reclaimed wastewater should be a resource in the near future, which will help to improve water management. Then, wastewater treatment, reclamation and reuse must play an important role in the increase of the resources of the oasis, but a complete study of the compatibility of crops, soil and reclaimed water is necessary, as well as the establishment of reuse practices.
- The studies of the authors [19,20] show that there are limitations with respect to the reuse of treated wastewater, especially in terms of bacterial pollution. The improvement of wastewater treatment is necessary to increase water availability using the non-conventional water resource.
- Communication with the inhabitants on the availability of water resources, water pollution and wastewater management and erosion control is a must. Nevertheless, is paramount to consider with absolute respect the traditional agricultural practices of the area, which sometimes have been abandoned. Given the tradition of the village—meetings of the responsible person with the stakeholders to explain the policies to be implemented—this communication should be easy.

(c) Several long-term actions are suggested:

- Groundwater needs special protection measures, and its relation with runoff and reclaimed water should be carefully controlled.
- Several technical features of the new agricultural practices should be better explained to the end-users, like drip irrigation management and its technical basis.
- Finally, it is counselled that a strong relationship is to be created and maintained among the peasants, town hall and agricultural research centres, as well as with water management experts. The role of the

universities and the international collaboration is perhaps the basis for the future development of the town, apart from the political circumstances.

The previous remarks and the entire study are show that a sustainable management of water in the agricultural context of the Figuig oasis should consider all the water sources in relation with the entire agricultural cycle. This means that plants, soils and water should be considered as a whole, especially in terms of salinity management and soil losses. Agricultural productivity will depend heavily on this correct management also combined with the recycling of manure.

The abandonment of classical ways to recover water (i.e. foggaras) should be analysed in terms of efficiency and cost recovery. The mere existence of such practices and infrastructures is an addition to the touristic attractiveness of the town.

References

[1] P. Laureano, The water atlas. Traditional knowledge to combat desertification, UNESCO, IPOGEA/LAIA, Castello, Venice, 2001.

[2] A. Corsale, Popolazione e ambiente nelle oasi della fascia predesertica del Maghreb: evoluzione socioeconomica in relazione a le resorse idriche [Population and environment in the oases of the Maghreb pre-desert belt: socio-economic evolution in relation with the water resources], doctoral thesis, University of Cagliari (Italy), Faculty of Political Science—Section of Geography, Abstract published in the Saharan Studies Association Newsletter, July 2005, XIII (1), 2005.

[3] Britannica Online Encyclopedia. Available from: www.britannica.com/EBchecked/.../Figuig (July 2011).

[4] G.M. Meszoeli, Water resources management in a Saharan Oasis, Dissertation in partial fulfillment of the requirements for the PhD degree, North-eastern University, Boston, Massachussets, 2006.

[5] R. Makkaoui, J.-L. Dubois, Nouvelles formes de gouvernance dans le domaine de l'eau. Apports et limites de la coopération décentralisée dans les pays en développement [New forms of water governance: Contributions and limits of the decentralized cooperation in the developing countries], Développement durable et territoires 1(1) (2010) 2–19.

[6] A. Torrens, L. Alcalde, M. Salgot, P. Casanova, E. Queralt, O. Elhachemi, H. Elhalouani, C. González, Sustainable water resources management in the oasis of Figuig, Morocco, in: International IWA Conference on Sustainable Solutions for Small Water and Wastewater Treatment Systems, Girona, Spain, 2010.

[7] Figuig net, Milieu physique [Figuig net, physical environment]. Available from: http://www.figuig.net/figuig milieu physique/html (August 2011).

[8] A. Mohammi, Qualité des sols de l'oasis de Figuig [Quality of the soils of the Figuig Oasis], Revue H.T.E., 119—Juin 2001.

[9] Zousfana.com, Figuig: The water. Available from: http://www.zousfana.com/eau_figuig.aspx (August 2011).

[10] P. Breil, M. Combe, Le Haut Atlas oriental [The Eastern High Atlas], in: Rabat (Ed.), Ressources en eau du Maroc/Royaume du Maroc, du service géologique, t. III, Direction des mines et de la géologie [Water resources in Morocco/Morocco Kingdom, from the Geological Survey], Rabat, 1977, pp. 140–159.

[11] A. Bencheriffa, H. Popp, L'oasis de Figuig, persistence et changement [Figuig oasis, persistence and change], Passavia Universitätsverlag, Passau, 1990, p. 110.

[12] Ville Figuig info, Site officiel de la ville de Figuig [Figuig town info: official site of the town of Figuig]. Available from: http://www.ville-figuig.info/ (August 2011).

[13] Raddo.org, Réseau Associatif de Développement Durable des Oasis, Projet: Partenariat pour la réalisation du système d'assainissement de l'Oasis de Figuig [Raddo. org, Associative network for the sustainable development of oases. Project Collaboration for the implementation of the sanitation system of the Figuig Oasis]. Available from: http://www.raddo.org/ (August 2011).

[14] P. Casanovas, Hydrogeological study of the Figuig oasis (Morocco), Curso Internacional de Hidrología Subterránea; trabajo final de curso, 2010, in Spanish.

[15] H. de Haas, Migration and agricultural transformations in the oases of Morocco and Tunisia. Geographical studies of development and resource use, KNAG, Utrecht, 2001.

[16] O. Berkat, M. Tazi, Morocco: Country pasture/Forage resource profiles. Availabe from: http://www.fao.org/ag/AGP/AGPC/doc/Counprof/Morocco/morocco.htm. This profile was completed in January 2004 by the authors and was edited by J.M. Suttie and S.G. Reynolds in January/February 2004. Livestock data were updated in August 2006 by S.G. Reynolds (August 2011).

[17] WHO, Safe Water Use in Agriculture and Aquaculture, WHO, Geneva, 2006.

[18] P. Dillon, A. Kumar, R. Kookana, R. Leijs, D. Reed, S. Parsons, G. Ingerson, Managed Aquifer Recharge—Risks to Groundwater Dependent Ecosystems—a Review. Water for a Healthy Country Flagship. Report to Land & Water Australia, 2009.

[19] O. Elhachemi, Traitement des eaux uses par lagunage naturel en milieu désertique (Oasis de Figuig): Performances épuratoires et aspect phytoplanctonique [Wastewater treatment using pond systems in a desert environment (Figuig Oasis): treatment performances and phytoplanctonic aspect], Thèse de Doctorat es-Sciences, Université Mohammed Premier, 2012, p. 122.

[20] O. Elhachemi, H. Elhalouani, A. Torrens, M. Salgot, Wastewater treatment in the oasis of Figuig (Morocco) by facultative lagoon system: Physico-chemical and biological aspects, J. Life Sci. 6 (2012) 543–549.