Sustainable water resources management in the Oasis of Figuig, Morocco

In the Oasis of Figuig, Morocco, a sustainable management of the water resources in the Oasis shall be implemented that is focusing in the rational use of water in agriculture and wastewater reuse. This paper presents the activities carried out in the Oasis within the Project "Support to the public policy of water management in Figuig".

Authors: A. Torrens, L. Alcalde, M. Folch, Salgot, P. Casanova, E. Queralt, O. Elhachemi, H. Elhalouanih, C. González

Abstract

The Oasis of Figuig (Morocco) is located in Morocco's far South-east, near the Algerian border. Water resources are scarce in the Oasis and the sanitation is very poor. The community of Figuig requested technical assistance to improve the water management in the Oasis. This paper describes the activities carried out in the Oasis within the frame of a Programme of Support to the public policy of water management in Figuig funded by the ACCD (Agència Catalana de Cooperació al Desenvolupament). The tasks performed by the different teams that contributed to the project have been: the aquifer characterisation, the implementation of a water user's community, the planning and management of wastewater treatment and reuse, and the implementation of sensitisation and capacity building programs. The activities carried out have contributed to the planning and management of the water resources of the Oasis in a sustainable and integrated way. A global water management in the Oasis is absolutely necessary in order to gain sustainability and maintain in good conditions the scarce resources available.

Key facts:

- Water resources in the Oasis of Figuig (Morocco) are scarce and the sanitation is very poor.
- The community of Figuig requested technical assistance from the NGO Món-3 to improve the water management in the Oasis.
- The integral water management tasks included: the aquifer characterisation, the water users community implementation, wastewater treatment and reuse planning and management sensitisation campaigns and capacity building programs and the creation of a water analysis laboratory and a municipal water service.
- The neighbourhood (ksar) of Hammam-Foukani is the only one with a complete sanitation system: a sewerage system and wastewater treatment with waste stabilization ponds (WSPs).
- The sanitary quality of the final effluent met the irrigation water standards for restricted irrigation the entire year according to the WHO recommendations (WHO, 1989) and the draft of the future Moroccan legislation on wastewater reuse. According to this, the final effluent can be used for the irrigation of trees (i.e. date palms).
- At present 1 ha of trees are being planted around the WSP to avoid the infiltration of sand in the ponds during sand storms and to prevent desertification. Part of this plantation is being irrigated with the WSP effluent.
- The Water User's Community with capacity building and sensitisation campaigns has totally changed the perception of the population about the use of treated wastewater: from a dangerous waste to an additional water and fertiliser source.
- The water analysis have also contributed to the acceptance of wastewater reuse practices, as the regular monitoring of the WSP effluent creates confidence in the population about the quality of this new source.

Introduction

Water shortage is currently one of the biggest concerns worldwide. According to the Kyoto summit in 2003, two billion people will not have access to safe drinking water supplies by 2015. The Mediterranean countries belong to the most affected regions by water scarcity (Bdour et al., 2009).

Morocco is characterized by an arid to semi-arid climate with occasional long periods of drought caused by extreme weather conditions. Moreover, water resources are unevenly distributed. Indeed, these resources are evaluated at about 30 billion m^3. Only 11.5 billion m^3 can be used and 93% serve for irrigation of 1.2 million ha. With an increasing urban population, Morocco is at the limit of hydric stress and a deficit of about 500 Mm^3 of fresh-water is expected by 2020 (Thari et al., 2010). Therefore, it is essential to develop new water resources, especially for agriculture. For this reason, an integrated water management, including reclaiming wastewater for agricultural use, is an essential strategy to increase water resources. The integrated water management will offer long term social and technical solutions.

The Oasis of Figuig (Morocco) is located in Morocco's far South-east, near the Algerian border, at an average height of 880m and has an estimated population of 15,000 inhabitants. The climate is Saharan, consisting of cold winters (with a minimum temperature of 3,8 ºC) and hot summers (with a maximum temperature of 43,1 ºC). There are often severe drought periods when the rainfall only reaches 50mm, and occasional heavy rains that cause floods and damages. The main economical activity of the Oasis is date production. The total surface dedicated to date cultivation is about 700ha with an estimated 150,000 palm trees. The municipality of Figuig is divided in seven quarters (ksour).

Water resources are scarce in the Oasis. The main water resource of the community is groundwater, through wells, natural sources and mines (foggaras). This water is used for potable consumption and agricultural irrigation (mainly palm trees) (Figure 1). The main irrigation technique in use is border irrigation, which represents a large waste of water. Over the last years, there has been an increase of the arable land mainly due to the proliferation of new wells built without any control. This situation has lead to an overexploitation of the aquifer resulting on a salinisation of the groundwater resources as well as the soil.

On the other hand, sanitation is very poor. Most houses are only provided with septic tanks or cesspits. Although part of the community has a piped sewerage system this is still not in use since the wastewater treatment plant has not been constructed yet. The main problem associated with poor wastewater management is the contamination of the aquifer. Hammam-Foukani is the only ksar with a complete sanitation system: a sewerage system and a waste stabilization pond (WSP). The WSP was built in 1998 in order to treat and reuse the wastewater for agricultural irrigation purposes. However, the system was not well maintained and the monitoring of the ponds, in order to evaluate the correct performance of the system and the quality of the final effluent was not carried out. Therefore, this non-conventional resource of water was not used.

The community of Figuig requested technical assistance from Món-3 to improve the water management in the Oasis. Since 1999, Món-3 and several research teams from the University of Barcelona (UB) have been collaborating with the municipality of Figuig for the implementation of a sustainable management of the water resources in the Oasis. This paper presents the

Figure 1. Figuig Oasis: water storage and distribution systems

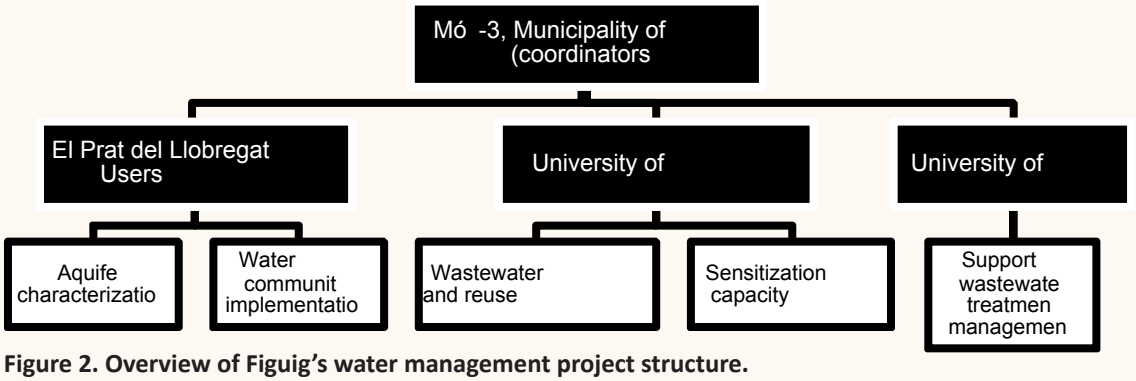

Figure 2. Overview of Figuig's water management project structure.

activities carried out in the Oasis by the Water Resources Group of the University of Barcelona, the University of Oujda and the Irrigation Community Association of El Prat del Llobregat within the frame of a cooperation programme designed by Món-3 and the municipality of Figuig for the public policy of water management.

The project structure and approach

The Programme "Support to the public policy of water management in Figuig" is divided into specific task groups as outlined in Figure 2. The project has a multidisciplinary approach including technical experts of different disciplines: hydrology, chemistry, geology and biology. The project manager (Món-3) oversees all aspects of the project in coordination with the Municipality of Figuig, to ensure all key decisions are transmitted to the community. For the major activities of the project a community consultation has been put in place to ensure that the outcome is in line with the community expectations.

Project tasks

Aquifer characterization

A study was carried out to establish the quality of the ground water; the water budget and the magnitude and direction of hydraulic gradients. These campaigns were carried out with numerous sampling points (Figure 3) taken during 2008 measuring piezometric levels, in-situ parameters (electrical conductivity (EC), pH and temperature) and chemical analysis (HCO_3^-, SO_4^{2-}, Cl^-, NO_3^-, Na^+, K^+, Ca^{2+}, Mg^{2+}, NH_4^+). The analyses were performed according to APHA (2005). The analysis of some chemical species from Piper, Schöeller and Stiff modified diagrams, from the ionic relations and geochemical ratios (r SO_4^{2-}/r Cl^- , r Cl^-/r HCO_3^-), made possible to determine the groundwater flow direction from piezometric data's (Figure 3). The geological characterisation of the area is based on the study made by Bencheriffa and Popp (1990).

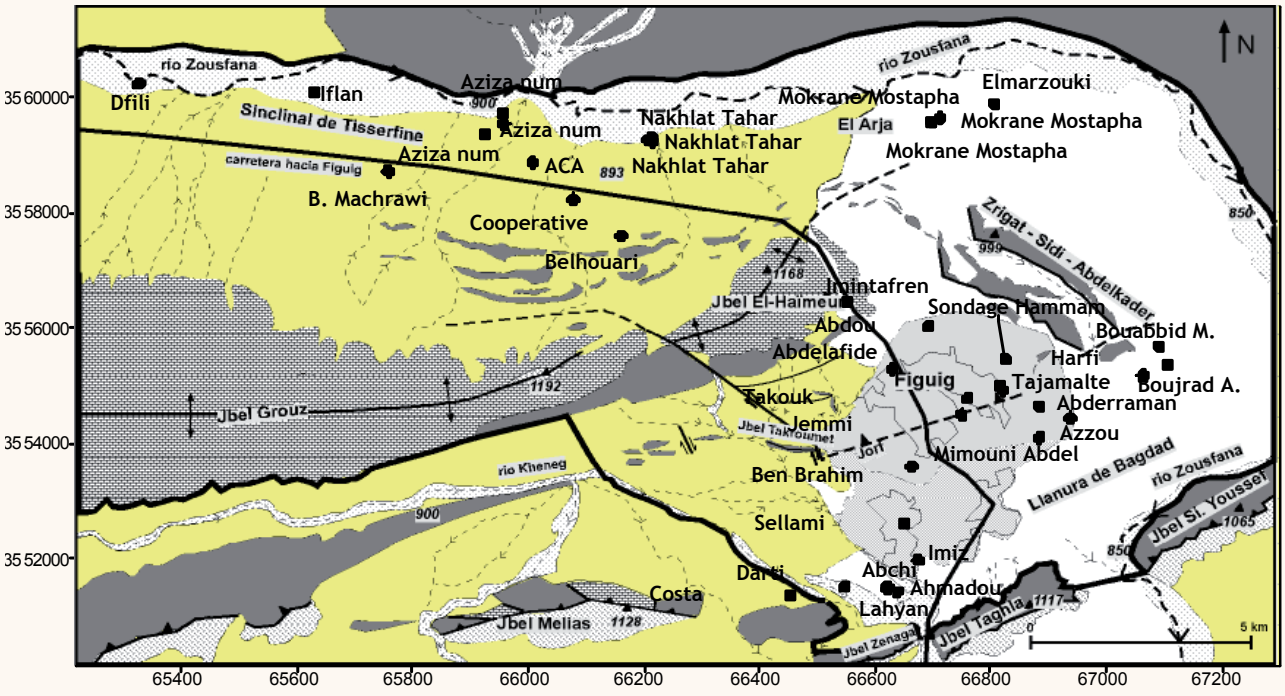

Figure 3. Map of the water sampling points (38) used in the hydro-geological study

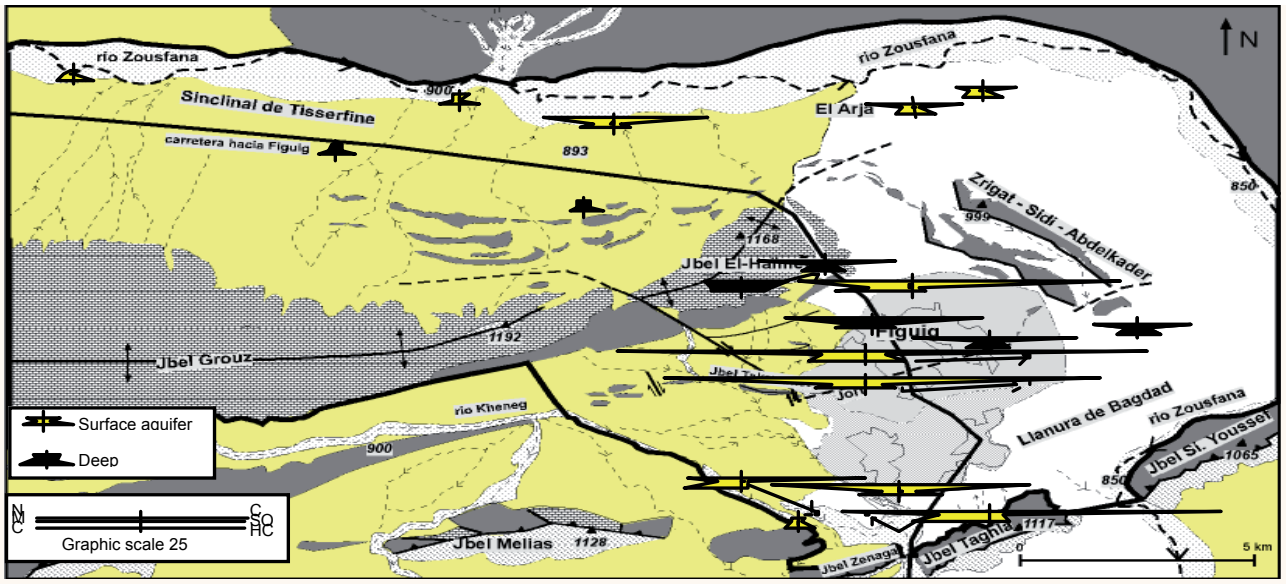

Figure 4. Representation in Stiff modified diagram of data results from the campaigns

The community of Figuig has two aquifers: a superficial 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 the population with drinking water. The groundwater level measurements, the parameters in-situ and the samples analysed from the different wells monitored, determined the flow direction of both aquifers (Figure 4).

Chemical analysis show that 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 content of nitrates found in some samples of Figuigs aquifers is linked to intensive cultivation (small plots with high density of cultures) and the presence of farms nearby wells and water sources in the surface aquifer. The northern areas of the Oasis have a higher quality of water for agricultural purposes; while in the south water has a poor quality for irrigation. The concentrations of nitrates and chlorides indicate a low quality of water for human consumption according to Moroccan legislation and WHO recommendations.

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

The evaluation of the aquifer characteristics has lead to determine the quantity and quality of the groundwater, so it proves to be a useful tool for the community for managing the water resources of the Oasis. It is also a useful tool for planning the actions to be taken (i.e. wastewater reuse, managed aquifer recharge) in order to assure a long term availability of the water in the Oasis.

Water user's community implementation

The Oasis of Figuig holds a structure of water use dating back a thousand years. The water administration has been carried out by the locals using an irrigation infrastructure based on flood irrigation. Generally, the structure of each irrigation association is based on a source, a distribution network and several culture lands interspersed within the urban area of the Oasis. The gradual increase of the wells extraction together with the alleged effects of climate change have caused problems of water availability in some of these communities, underlining the fragility of the Oasis.

Based on this analysis, Món-3 began to cooperate in 2006 with the "Comunitat d'usuaris d'aigua del Delta del Llobregat" (CUADLL) in order to create a global community of water users similar to the Water Users Community of the Llobregat (Queralt, 2007). The Figuig Water Users Community is composed by 12 members who were elected by the community and are representative of every ksar. Therefore, it covers all the water uses of the Oasis (including the Municipality's) in order to reinforce a sustainable management of the Oasis scarce water resources. Following several brainstorming sessions in Barcelona and Figuig the statutes of the water users' community were approved and it was officially constituted during the International Water Forum held on 5th and 6th of November 2007 in Figuig. Currently, the Water Users Community has implemented a control network of aquifer levels and has installed two pluviometers to

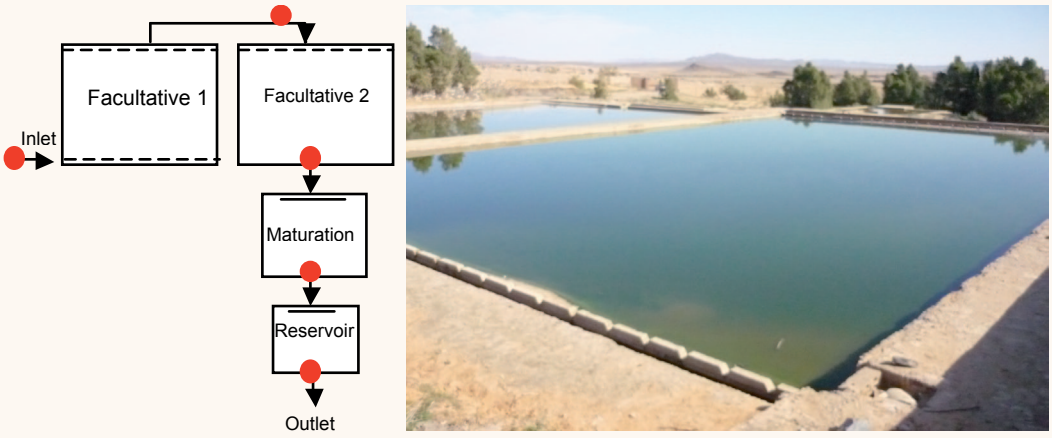

Figure 4. Flow diagram of Hammam Foukani's WSP, sampling points and view of the facultative ponds

control de water budget. The community is also participating in the wastewater reuse planning (inventory of the current cultures and the potential ones, farmers information on the amount of land and type of cultures that could be irrigated with reclaimed water,..). In the near future, a 40 km water transfer from a reservoir will be in operation and the Water User's Community of Figuig will be responsible for managing and distributing this water.

The implementation of a Water Users Community that takes into account and includes all water users facilitates the integrated water management of the Oasis. The creation of Water Users Community has also established a collective conscience and the problem of over exploitation of groundwater is now perceived as a community concern.

Wastewater treatment and reuse planning and management

The Hammam Foukani WWTP started operating in 1998 and has 3 ponds in series (2 facultative and 1 maturation pond) and a reservoir for irrigation (Figure 4). The population served is approximately 1200 PE and it has an average flow of circa 70 m^3/day.

The average overall loading received by the plant is of 142 kg BOD_5/ha/d. The main characteristics of the WSP are shown in Table 1.

Before the monitoring programme implementation, several corrective measures were done in the WSP:

- Desludging of the first facultative pond, as the volume of the pond was reduced more than 1/3 due to sludge and sand accumulation.
- Elimination of macrophytes that had invaded all the ponds.
- Construction of a sand barrier (wall and trees) to avoid the infiltration of sand in the ponds during sand storms.
- Cleaning of the inlet and outlet structures.

After these corrective measures a monitoring programme was conducted. Physicochemical (Electrical conductivity (EC), pH, COD, SS, BOD_5, $N\text{-}NH_4^+$, $N\text{-}NO_3^-$, $P\text{-}PO_4^{3-}$), microbiological (Fecal coliforms (FC) and helminth eggs) and biological parameters (algae characterisation and quantification) were monitored from October 2008 to November 2009 making a total of 8 campaigns (2 campaigns per season). Samples were taken in each unit process of the WWTP. Analyses were performed according to Standard Methods (APHA, 2005). Analyses for helminth eggs were performed also in the extracted sludge of the pond according to Bouhoum & Schwartzbrod (1989). Table 2 presents the WSP average effluent quality and total removal efficiency.

The inlet concentrations are high but characteristic of a wastewater from the small communities in Morocco (El Hamouri et al., 2003; Mustapha, 2009). The WSP

Table 1: Design characteristics of the WSP of Hamman Foukani.

Ponds	Volume (m^3)	Surface (m^2)	Depth (m)	HRT* (days)
Facultative 1	812	650	1,25	10
Facultative 2	812	650	1,25	10
Maturation 1	244	315	1	3
Reservoir	200	100	2	1

*hydraulic retention time

Table 2. Average concentrations and total percentage removal of the WSP for the main physicochemical and microbiological parameters.

Parameters	Inlet	Facultative 1	Facultative 2	Maturation	Reservoir	Total removal
pH	7,4	8,1	8,2	8,4	8,4	-
EC (mS/cm)	3,2	3,3	3,4	3,4	3,4	-
COD (mg/L)	556	320	254	233	225	58 %
BOD_5 (mg/L)	350	290	210	177	175	51 %
SS (mg/L)	289	190	174	155	151	48 %
$N\text{-}NO_3^-$ (mg/L)	*	*	*	*	*	-
$N\text{-}NH_4^+$ (mg/L)	42	29	23	17	17	57 %
$P\text{-}PO_4^{3-}$(mg/L)	11	7	6	5	4	60 %
FC (log)	7,7	6,6	5,7	4,7	4,4	3,3 log
Helminth eggs** (eggs/L)	35	-	-	-	n.d.	-

*$N\text{-}NO_3$ concentrations <0.5 mg/L

**Helminth eggs were analysed at the inlet and outlet of the WSP, n.d. = not detected

performed well taking into account the short HRT (Hydraulic Retention Times) of the original design. The sanitary quality of the final effluent met the irrigation water standards for restricted irrigation the entire year according to the WHO recommendations (WHO, 1989) and the draft of the future Moroccan legislation on wastewater reuse. According to this, the final effluent could be used for the irrigation of trees (i.e. date palms). The average concentration of FC in warm periods was about 3500 CFU/100 mL, which almost reaches the limit for unrestricted irrigation (3000 CFU/100 mL). The WSP was meant to produce an effluent able to be reused for unrestricted irrigation; however the designed HRT were too short to obtain such a good quality.

Organic matter (BOD_5, COD) and SS concentration at the final effluent were high, due to the high organic load that receives the pond and the short HRTs. Fluctuations in the effluent quality were observed according to the season. COD, BOD_5 and SS concentrations were higher during the warmer periods due to the presence of algae, as confirmed by the algae quantification. On the other hand the removal of FC was higher in summer (> 4 Ulog) when the concentrations of algae were important. High ambient temperature, solar radiation and pH due to the growth of algae have been reported to encourage pathogen inactivation and die-off (Davies-Colley et al., 1999).

The EC of the final effluent was about 3,5 mS/cm which is often lower than the groundwater EC used in the oasis for palm trees irrigation. It is necessary to underline that palm trees support water EC higher than 5 mS/cm.

If an unrestricted irrigation is required, the addition of a maturation pond or a complementary treatment (e.g. constructed wetland, sand filter) would improve the FC removal and would contribute to achieve the quality required. Moreover, if a constructed wetland, a sand filter or a rock filter as a complementary treatment is added, the high amount of SS (algal SS) of the WSP effluent would be reduced. In case of drip irrigation implementation, these post treatments would be mandatory.

The sludge extracted from the pond was placed in mounds over the sand beside the WWTP. The sludge samples taken from the surface of the mound presented 0,57 helminth eggs/g DM (dry matter) (Trichuris sp.). The WHO guidelines (WHO, 2006) for sludge reuse in agriculture recommend (<1 helminth egg/g DM). This sludge can be, therefore, used as agricultural amendment. On the contrary, the sludge samples taken much deeper from the mounds presented more than 1 helminth egg/g DM. Therefore if the sludge must be reused in agriculture it is necessary to spread it in thin layers over the sand to guarantee the sanitary quality.

At present 1 ha of trees are being planted around the WSP to avoid the infiltration of sand in the ponds during sand storms and to prevent desertification. Part of this plantation is being irrigated with the WSP effluent. Nowadays, and with the consultation of the Water Users Community of Figuig and the associations of farmers of Hammam Foukani, an agriculture wastewater reuse programme is being designed. The programme will take into account the type of cultures, the amount of land for cultivation, the soil characteristics and the irrigation techniques.

Figure 5. Sensitisation and capacity building interventions

Based on the analysis of the performance of Hammam Foukani's WSP, another study is being carried out regarding the design and location of the future WWTP that will treat the wastewater of all the Ksour of the Oasis in order to generate reclaimed water. The reclaimed wastewater of the future WSP is planned to be used for agriculture and urban irrigation.

Sensitisation campaigns and capacity building programs

Several sensitisation campaigns on efficient water use (water savings), sanitation and wastewater reuse acceptance were conducted from 2007 to 2010. The campaigns addressed farmers associations (6 campaigns), women associations (2 campaigns) and quarter associations (3 campaigns) as well as different schools (2 campaigns). The sensitisation campaigns were performed in collaboration with the University of Oujda in order to provide a local approach to the population. These campaigns were a success with a high number of participants turn up.

Capacity building interventions included two training courses addressed to the members of the local institutions searching to improve the capacity building of the local community on water resources management. These courses covered some theoretical but mainly practical aspects such as operation and maintenance of WSP, laboratory techniques (physicochemical and microbiological parameters), reuse-oriented wastewater management, irrigation good practices and potabilisation issues. These courses enabled the transfer of an up-to date knowledge to technicians and administrative staff as well as other stakeholders with some practical experience in the field. Regarding wastewater reuse acceptation, these sensitisation campaigns and knowledge transfer to different actors, have made change the perception of the population of Figuig regarding the reuse of treated wastewater, as a safe and necessary source of water.

Additionally a large training course on water analyses has been performed from 2010 to 2012 due to the fact that a laboratory of water analyses has been created within the framework of the project.

Water analysis Laboratory and Water Service

Due to the isolated situation of the Figuig oasis, and thus the difficulty on the realisation of water analysis due to the transportation time and costs; a laboratory for water analyses was constructed and equipped in 2010. A building was restored to implement the Municipal Service of Water (that is in nowadays in charge of the water management in Figuig) and the water analysis laboratory. The headquarters of the Water Users Community is also located in the laboratory building. The laboratory is in operation now (Figure 6), and the person in charge of it has been trained in the frame of the project by

Figure 6. Municipal water and sanitation service and water laboratory.

experts from the University of Oujda and Barcelona. The laboratory allows the control of potable water, wastewater, treated water and irrigation water by the community itself. Nowadays a municipal regular monitoring of the pond wastewater quality has been implemented, encouraging the reuse of the wastewater for the irrigation of date palms.

Challenges, recommendations and conclusions

The activities carried out in the frame of the Project "Support to the public policy of water management in Figuig" have contributed to the planning and management of the water resources of the Oasis in a sustainable and integrated way. An integrated water management in the Oasis is absolutely necessary in order to gain sustainability and maintain in good conditions the scarce resources available.

The characterisation of the aquifer is an essential tool to know and predict the quantity and quality of ground water available for the different uses.

The implementation of a Water Users Community including all water users facilitates the integrated water management of the Oasis.

Ponds systems seem to be an adequate technology for the wastewater treatment and reuse in an Oasis context, due to its good performance in these climate conditions and the low operation and maintenance costs. The use of treated wastewater for irrigation (mainly date palms) could be an important non-conventional resource that could solve the water shortage.

At present 1 ha of trees are being planted around the WSP to avoid the infiltration of sand in the ponds during sand storms and to prevent desertification. Part of this plantation is being irrigated with the WSP effluent. Nowadays an agriculture wastewater reuse programme is being designed. The programme will take into account the type of cultures, the amount of land for cultivation, the soil characteristics and the irrigation techniques.

Sensitisation campaigns are necessary for the public awareness on the water quantity and quality problems. Capacity building is essential for an autonomous and correct water resource management by the members of the community.

Before the implementation of the different projects activities the majority of the population of Figuig did not accept the reuse of wastewater as concept, even if talking about treated or reclaimed wastewater. The implementation of the Water User's Community with the capacity building of some members, the sensitisation campaigns and the monitoring of the pond, has totally changed the perception of the population about the treated wastewater: from a dangerous waste to an additional water and fertiliser source.

The creation of the waster service with the laboratory of water analysis has also contributed to the acceptance of wastewater reuse practices for the population, as the regular monitoring of the pond inspires confidence to the population about the quality of this new source.

The multidisciplinary approach of the project has permitted to evaluate integrated up-to-date information in the different fields of the water resources management, in order to provide solutions to all related aspects to the water cycle in a community.

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Name: Antonina Torrens
Organisation: Soil Science Laboratory, Faculty of Pharmacy, University of Barcelona
Town, Country: Barcelona, Spain
eMail: antoninatorrens@ub.edu

Name: Laura Alcade
Organisation: Soil Science Laboratory, Faculty of Pharmacy, University of Barcelona
Town, Country: Barcelona, Spain
eMail: lalcalde@ub.edu

Name: Miguel Salgot
Organisation: Soil Science Laboratory, Faculty of Pharmacy, University of Barcelona
Town, Country: Barcelona, Spain
eMail: salgot@ub.edu

Name: Montserrat Folch
Organisation: Soil Science Laboratory, Faculty of Pharmacy, University of Barcelona
Town, Country: Barcelona, Spain
eMail: mfolch@ub.edu

Name: Patricia Casanova
Organisation: Comunitat d'Usuaris d'Aigües del Delta del Llobregat, Avda
Town, Country: El Prat del Llobregat, Spain
eMail: pati_casdi@hotmail.com

Name: Enric Queralt
Organisation: Comunitat d'Usuaris d'Aigües del Delta del Llobregat, Avda
Town, Country: El Prat del Llobregat, Spain
eMail: equeralt@cuadll.org

Name: Ouafae Elhachemi
Organisation: Laboratory of Biology, Sciences Faculty, University Mohamed VI
Town, Country: Oujda, Marocco
eMail: ouafae.elhachemi@gmail.com

Name: Hassan El Halouanih
Organisation: Laboratory of Biology, Sciences Faculty, University Mohamed VI
Town, Country: Oujda, Marocco
eMail: elhalouanih@yahoo.fr

Name: Coco González
Organisation: Món-3 NGO
Town, Country: Barcelona, Spain
eMail: cocogonz@ub.edu