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Project reporting

Re-use of wastewater for a sustainable forest production and climate change mitigation under arid environments

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Abstract - Over the last decades biotic and abiotic constrains together with human actions are determining a substantial environmental pressure, particularly in dry lands as the south of the Mediterranean region. From very long time, indeed, simultaneous drivers such as demographic growth, climate change and socio-economic factors are weakening the previous homeostasis between human needs and natural resources on the regional scale. Resulting pressures are determining environmental degradation and increase of desertification risk for the arid and semiarid lands. Water quality and availability are both crucial points limiting people well-being and livelihoods in the same context. Scarcity of fresh water and heavy and mismanaged production of wastewater are the main factors affecting water resources. Increasing pollution of soil and ground waters reduces the possibility of sustainable development of local communities with relevant social consequences. The FAO's supporting program in north Africa aims to: a) develop new and cheaper phytotechnologies (e.g. constructed wetland system; innovative treatment system for reuse of waste water for fertigation); b) treat wastewater for water quality protection; c) promote land recovery by means of sustainable multipurpose forestry; d) adopt bioengineering interventions to stop slopes erosion and protect urban, and semi-urban infrastructures; e) create pilot demonstrative areas to test multi-purpose sustainable agroforestry systems. Within this frame, an integrated approach was designed to promote innovative sustainable water management and multipurpose forestry, in order to mitigate the effects of climate change, promote land recovery, and improve the livelihoods of local population. The present paper aims to provide an overview of the FAO project GCP/RAB/013/ITA. Particularly, two pilot studies are shown and discussed.

Keywords - phytotechnologies, arid environment, wastewater, sustainable development, forest and agroforestry systems

Introduction

The Mediterranean Basin with its climatic peculiarities is extended on three continents. It is densely populated (507 million people on 2010) and extremely rich of natural and cultural heritage. It constitutes an "ecoregion", where both social and economic developments are closely related to somewhat limited natural resources and vulnerable environments (FAO 2013).

After thousands of years of co-evolution between ecosystems and societies, human activities are determining substantial environmental pressure, with a large social-environmental imbalance between the northern and southern regions. Such disparities are exacerbated by climate change effects. These are causing an increase in intensity and frequency of the cyclical period of aridity and of extreme events such as wind duster and water bombs (IPCC 2012). The simultaneous action of biotic, abiotic and socio-economic factors is the main driver of land degradation and of increasing risk of desertification (Bennadji et al. 1998).

In arid and semi arid areas the soil is scarcely productive. In this context, forests can play a crucial role in promoting and restoring the water cycle on the regional scale (David et al. 2011, Matteucci et al. 2011).

Forests in drylands are an invaluable multipurpose resource of fodder for livestock, fuel-wood (e.g. 58% of all the energy consumption in Africa), non-wood and fiber products and biomass (FAO 2013). They also provide a wide range of environmental services (ESs) such as protection from soil erosion, addition of organic matter, increased water retention and biodiversity. ESs are particularly relevant for agricultural activities and desertification control. Afforestation and reforestation activities in arid and semi-arid lands are functional to soil rehabilitation/restoration. Forests increase carbon

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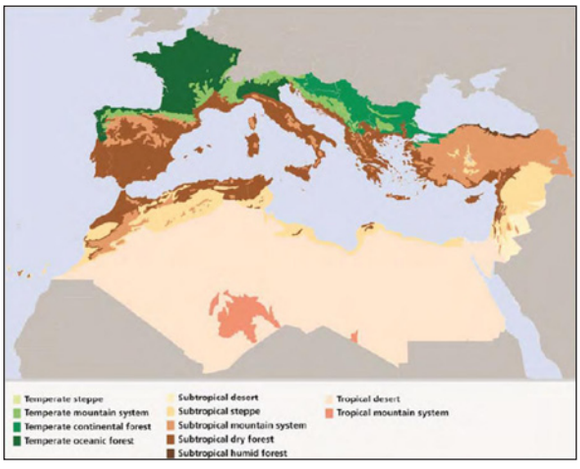

Figure 1 - Steppes and deserts dominates the southern Mediterranean countries. Source: Derived FAO and JRC, 2012 and Iremonger and Gerrand, 2011.

sequestration and storage, generate employment opportunities, provide recreational and landscape value (FAO 2013).

Water quality and availability represent crucial limiting factor for human well-being and livelihoods in arid and semi-arid lands.

The southern Mediterranean countries generally are dominated by steppes and deserts (Fig.1). Such environments are fragile and exposed to degradation and desertification processes.

Northern Africa, is affected by different problems heavily related to the new social and economical development. The population growth of the last decade highlighted the limits of available natural resources. The effects of global change together with new agricultural techniques (e.g. pivot irrigation), unsustainable water and soil management, land use changes led to an overexploitation of natural resources. All this is endangering the fragile balance between human needs and natural resources.

Especially in arid and semi-arid lands, the low availability of fresh water and the mismanaged production of wastewater are main factors affecting use and availability of water resources. Contamination of soil and ground waters biases, finally, any sustainability in the processes of local development.

A contribution to sustainability relies on the use or re-use of non-conventional water resources. Urban waste water can be properly treated and used for forest and agroforestry systems in rural, urban and peri-urban areas. This would increase the availability of wood, firewood, biomass, food and ecosystem services.

Over the last three years FAO Forestry has implemented new activities on the use of non conventional waters in forestry and agroforestry systems of arid zones in some Mediterranean countries. Through a collaboration with the Italian Ministry of Foreign Affairs, FAO launched the GCP/RAB/013/ITA project "*Forest restoration in Algeria, Egypt, Morocco and Tunisia using treated wastewater to sustain smallholders' and farmers' livelihoods*". In this project Scientific Italian Institutions (DIBAF-University of Tuscia, University of Basilicata, National Research Council CNR and Consiglio per la Ricerca e sperimentazione in Agricoltura CRA) in collaboration with the FAO Forestry Department have designed and developed pilot projects in Maghreb countries, innovative methodologies for a sustainable and cheaper use of urban wastewaters.

The project is an important example of participatory approach to the formulation of cooperation projects. Indeed, the project plan directly derives from the needs and requests of the four North African countries involved: Algeria, Egypt, Morocco and Tunisia. These countries specifically requested the Italian expertise to re-use treated wastewater for the restoration of forestry and agro-forestry systems of arid zones.

Project objectives

The main aim was the use of non-conventional waters for irrigation of multipurpose wood plantations for tree crops' production, orchards, fuel-wood and wooden biomass. In particular, the project proposed an integrated approach specifically aimed to: a) reduce pollution of natural water resources (development of new and cheaper phytotechnologies for wastewater treatment); b) mitigate climate change, promote the recovery of degraded areas, reducing contamination risks of ground water and soil; c) improve the living conditions of the local population through forestry and agroforestry sustainable activities, taking into account needs and traditions of local people.

Materials and Methods

The methodologies adopted by the project to treat wastewater are mainly two: constructed wetlands (phytotechnology approach) and a modified version of the standard wastewater treatment system, planned to reduce the energy inputs and preserving the nutrient load useful to the plants (fertigation approach).

Constructed wetlands

Natural wetlands act as bio-filters, removing sediments and pollutants from the water; constructed wetlands are designed to emulate these features. Vegetation in a wetland provides a substratum (roots, stems, and leaves) upon which microorganisms can grow as they break down organic materials. The plants remove about 70% to 90% of pollutants

(biotic and abiotic), and provide carbon for micro-organism particularly by fine root turnover. Constructed wetlands are largely recognized as effective for primary and secondary urban and agricultural wastewater treatment (Kadlek 1996, US_EPA 1999), and are considered by the World Health Organization (WHO) an effective and cheap way to meet its microbiological guideline for wastewater reuse (WHO 1989). These systems are made up of ponds placed in sequence, filled with specifically selected plants, shrubs and vegetation for their ability to filter impurities from the water. The treated water is then let settle in storage basins. Since the system only uses natural phytotechnology solutions it also appears to be more sustainable and economically-viable for rural communities. The application of this system in Algeria and Tunisia has been designed by researchers of the University of Tuscia, Italy.

Innovative treatment for reuse of waste water for fertigation

Innovative "secondary" treatment for wastewater systems reduces the microbial load to acceptable limits, maximizing the release of useful substances (e.g. Nitrogen and Phosphorus), which can be used in agroforestry systems to provide nutrients and organic matter in the soil. According to this innovative approach a methodology was developed by the University of Basilicata, Italy, after a testing phase on olive trees. From these previous pilot studies, it has emerged that properly controlled modifications of a conventional treatment plant, together with an accurate monitoring scheme which adjusts the provision of organic matter and nutrients to the irrigated soil, is a cost-effective system that maximizes the amount of “good” organic matter available for irrigation, while minimizing health risks.

Main activities supported in the project countries

In response to the specific requests of the participating countries the project is supporting

- In Morocco, the establishment of 10 hectares of palm grove that will be part of the green belt of the town of Marrakech (31°42’3.02”N – 8°3’37.25”W). The green belt will have several functions including agro-silvo-pastoral activities and to act as buffer zone between the main landfill and the urban area. The plantation is irrigated by the innovative treatment for reuse of wastewater for fertigation designed by University of Basilicata, and realized in collaboration with University of Marrakech. Both CNR and CRA have provided further support in the development of the plantation. This plantation will be included into the larger project for the development of "green belt" to protect the city against soil erosion, desertification and to create a functional zone for the development of agroforestry activities. At the same time, the use of fertigation techniques will ensure an increase of soil fertility and carbon storage capacity of the soil.
- In Egypt the project provided the drafting of the first forestry management plan of Serapium forest (30°29’24.41”N -32°13’59.77”E, Ismailia district), which is a 25 years old plantation irrigated with treated wastewater. The Serapium plantation (129 ha) was realized using different species (*Eucalyptus citriodora Hook.*, *E. camaldulensis Dehnh.*, *Casuarina equisetifolia L.*, *Cupressus sempervirens L.*, *Khaya senegalensis* (Desr.) A. Juss, and others) adapted to hot environments and characterised by a high wood productivity. The forest management plan has been drawn taking into account the possibility of making this forest eligible for a possible market for carbon credits. The work is being carried out by the Under-Secretariat for Afforestation and Environment of the Ministry of Agriculture, the Department Forestry University of Alexandria and other relevant Egyptian institutions, under the technical coordination of FAO and with the support of the University of Monaco (Germany) and University of Tuscia (Italy).
- In Tunisia the project activities have been implemented in Ouechtata, a rural village in northern Tunisia, close to the coast (36°57’27.51”N – 9°00’7.29”E). The activities concern the design of a constructed wetland, planned to reduce the pollution of a water reservoir used for agricultural needs, at low cost and in sustainable way. Furthermore, the design of a fertigation system for olive trees and biomass production in Hafouz (inside village of southern Tunisia, 35°38’13.21”N – 9°42’28.44”E) is planned to reduce the cost of management of the already existing wastewater treatment plant. The activities were conducted in close cooperation among the project partners (FAO, University of Tuscia and University of Basilicata) and the national Forestry General Direction.
- In Algeria the FAO project supported the completion of an already existing pilot area in the Oasis of Brézina (33°5’38”N – 1°15’3.40”E). The project was developed in the context of the Italian cooperation (Ministry of Economic Development - MISE, Ministry of Foreign

Affairs - MAE), by the University of Tuscia (IT) and University of Mascara (ALG). The reuse of the wastewater produced by the local community was tested for the irrigation of forestry and agroforestry systems, after treatment by means of the constructed wetland technology. A second activity was the design of constructed wetlands to reduce the pollution of the local river and of the palm plantations, as well to fight the erosion processes in the oasis of Taghit (30°55'3.06"N – 2°2'2.22"W).

Pilot applications of phytotechnologies to realize productive and protective forest systems in southern Mediterranean countries: two case studies.

Phytotechnologies use plants to remediate various media impacted with different types of contaminants (Vangronsveld et al. 2009, Otte and Jacob 2006). In different sites in north Africa, the integrated systems to reduce water and soil pollution have been designed and developed (treating the urban waste water by constructed wetland). At the same time, these systems are planned to promote land rehabilitation (planting trees according to multipurpose scheme and local needs). Below, two pilot applications carried out in Algeria are explained briefly.

First case study

Oases are the main spots of human development in desert areas. Biotic and abiotic constraints together with human actions determine the fragile equilibrium of the ecosystem that is threatened by desertification.

In the oasis of Brézina an integrated, sustainable model for the oasis protection, recovery and development has been recently realized, also considering the advantages related to carbon credits market through the Clean Development Mechanism (CDM) of the Kyoto Protocol. Brézina oasis is located in the pre-Saharan region (800 m a.s.l.), 85 Km south of the county (*wilaya*) town of El Bayadh, Algeria. Brézina is characterized by a pre-Saharan arid climate, with an annual mean temperature of 20 °C; diurnal variation of 11 °C; annual rainfall rarely exceeds 100 mm (NASA 2007); low atmospheric humidity (around 40%); high solar radiation (16.56 MJ $m^{-2}day^{-1}$) and high wind speed. During the April dust storms, the average wind speed grows until 5.9 m s^{-1} (Kasbadji Merzouk 2000). The *Seggueur* ephemeral river, which surrounds the oasis at the southern side (Masini et al. 1988), is the main source of water for the palm plantation and for the traditional agricultural productions, performed under the palm cover of the oasis.

The main problems which afflict Brézina oasis are related to the groundwater depletion resulting from increasing urban population, excessive retention of *Seggueur* river by the dam realized upstream of the oasis, and climate change. All these are causing severe damages of the palm grove and the risk of groundwater contamination due to the outflow of untreated wastewater.

The main goal was to face the challenge from two different perspectives. The first concerns the adoption of a new water management model, inspired to the collection, recycle and reuse of urban wastewater. The second proposes a new agroforestry strategy in order to stimulate both alternative economic chains and environmental restoration. The recent Oasis growth suggested to design a system optimised for the local conditions and easily expandable. For this reason the pilot project was designed as a modular system, able to be replicated in parallel or in series to match increased wastewater flow rate or pollution, respectively. The modular approach implies the definition of a minimum flow rate of wastewater. Such a minimum quantity is collected, treated and, finally, reused through a single process. The wastewater pilot system was designed to fill a good quality of output and to reduce the infiltration and evapotranspiration losses using constructed wetlands. A further target was to build up a simply operated and flexible system, in terms of effluent quality produced (Mara 1999).

Two parallel natural treatment chains compose the system, as illustrated in Figures 2-3-4:

1) CW B is a constructed wetland with horizontal superficial flow, being composed by three cells alternating aerobic (cell 1 and cell 3) to anaerobic process (cell 2) (Fig. 3).
2) CW A is a constructed wetland with horizontal sub superficial flow composed by three separated cells where mainly aerobic processes are triggered (Fig. 4).

Both treatment chains are connected with a storage basin necessary to homogenize the flow rate variation during the day and to provide minimal water storage. For the constructed wetland were chosen two different mixes of plant species (Fig. 5):

- MIX 1: *Phalaris arundinacea* L., *Juncus* spp., *Phragmites* spp., *Typha* spp., optimal for reduced water depth and resistant to short periods of dryness.
- MIX 2: *Myriophyllum* spp., *Thypha* spp., optimal to favor anaerobic processes.

The synergistic effect of hydraulic design, the plant species selection and the related fine root biomass promotion, improve the process of ab-

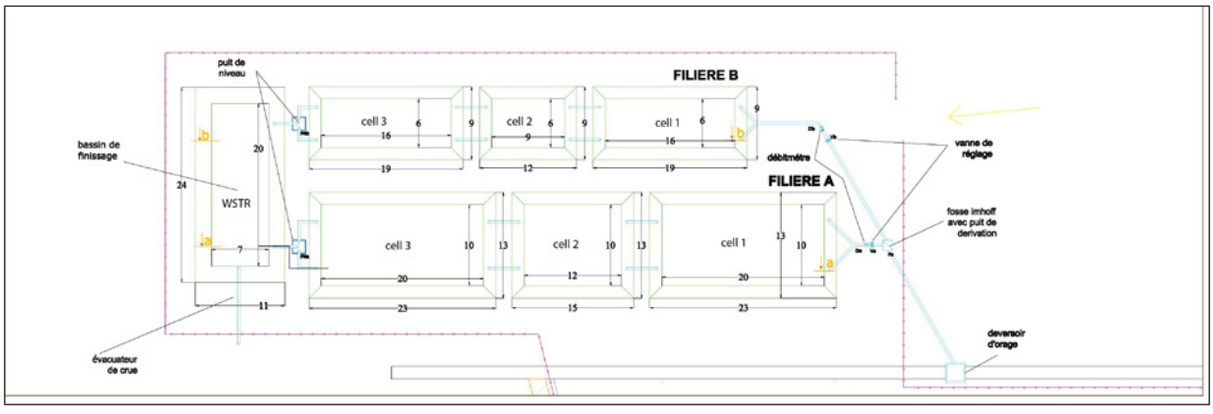

Figure 2 - Oasis of Brézina (Algeria) – waste treatment system: plan.

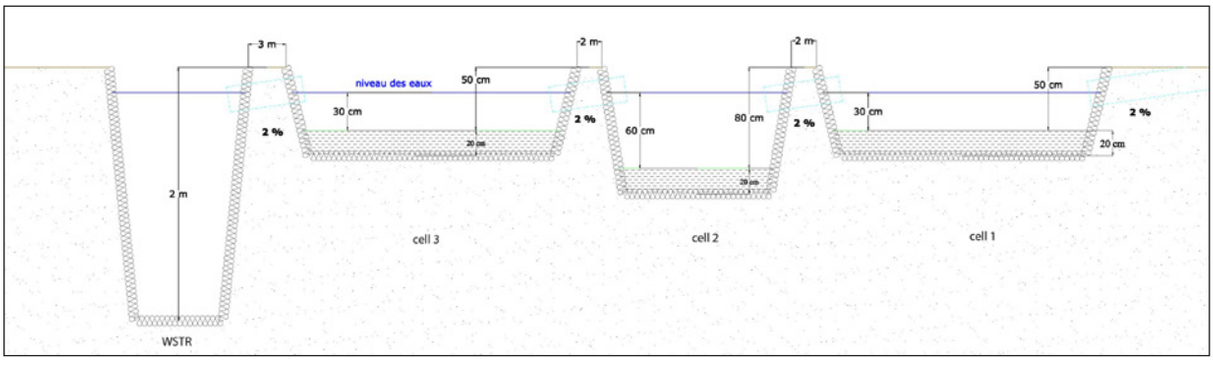

Figure 3 - Oasis of Brézina (Algeria) – CW B section: a constructed wetland with horizontal superficial flow. Cell 1 is designed to provide preliminary sedimentation with a water level up to 30 cm, the vegetation is emergent with a density of 90%. Cell 2 is designed to provide anaerobic digestion of Cell 1 effluent, water level never exceed 60 cm and the vegetation is submerged with a density of 20%. Cell 3 is designed to complete the water treatment of Cell 2 effluent trough aerobic process. Water level is up to 30 cm and vegetation is emergent with a density of 90%. WSTR (Water Storage Treatment Reservoir).

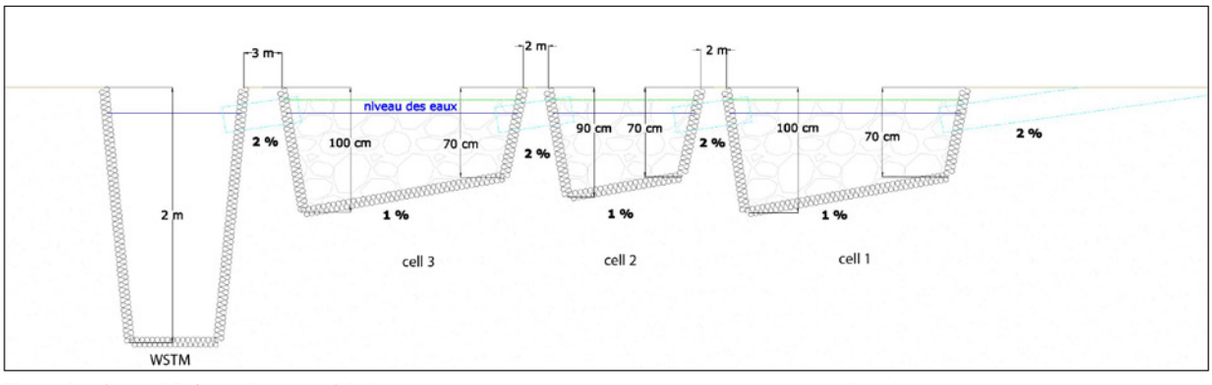

Figure 4 - Oasis of Brézina (Algeria) – CW A section: a constructed wetland with horizontal sub superficial flow composed by three separated cells where mainly aerobic processes are triggered. WSTR (Water Storage Treatment Reservoir).

sorption, sedimentation and inactivation of major pollutant as BOD5 (biochemical oxygen demand of wastewater during decomposition occurring over a 5-day period), TSS (total suspended solids), nitrogen, phosphorus and *Escherichia coli*.

The treated wastewater is efficiently reused into the forest agroforestry plots, using drip irrigation. The forest specie selection maximizes both environmental and economical improvement through marginal land restoration, no-food products, and potential revenue from carbon sequestration (Fig. 6).

In the forest plantation four experimental systems were tested.

Figure 5 - Oasis of Brézina (Algeria) – view of the constructed wetlands in October (2013).

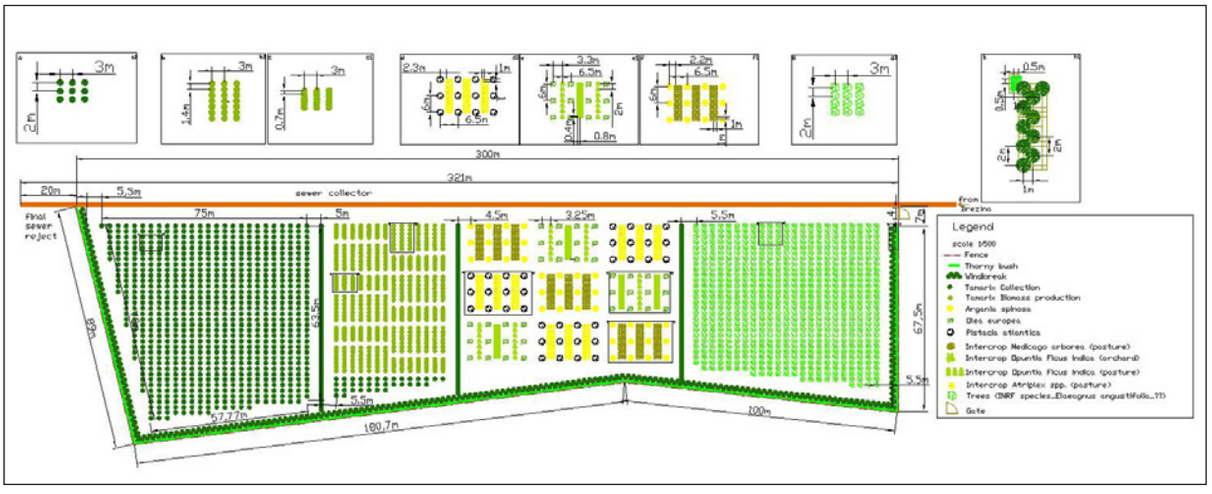

Figure 6 - Oasis of Brézina (Algeria) –agroforestry testing plots: species (wood and forage), densities (biomass) genotypes evaluation.

1. *Tamarix* spp. collection to compare different species and populations for plant breeding.
2. *Tamarix* spp. plantation for biomass production under short rotation regime to evaluate productivity, inter-annual growth rates, wood quality also for bioethanol production, environmental benefits.
3. Plantation of different species with a relevant ecological and economical value to produce forage, wood and non-wood products (e.g., *Argania spinosa* L., *Pistacia atlantica* Desf., *Olea europaea* L.). The trees were planted at a distance of 6 m, on 7 m spaced rows; the inter row will be planted with forage intercrop species: *Atriplex* spp., *Medicago arborea* L., and *Opuntia ficus-indica* (L.) Mill.
4. Experimental comparison on field for genotype evaluations of *Populus* spp. in order to select suitable plant material for forestry plantations in arid and semi-arid lands.

Second case study

Along with the objective of preserving oasis ecosystems, Algeria has opened several national programs for environmental protection and local development, as the one for Taghit Oasis. This program is focused on the identification of measures able to protect the environmental resources and cultural heritage, promoting a sustainable development of a vulnerable area, transformed by human activities for centuries, at present under the pressure of new societal drivers. From this perspective, the oasis of Taghit represents a small-scale experiment to test new approaches for environmental protection in the frame of the sustainable development of the Oasis.

In Taghit the project aims to reduce the impact of wastewater on the principal river, where the palm cultivation is managed in combination with agro-pastoral activities. In fact, as consequence of an increasing wastewater discharge and of increasingly frequent events of flooding, the fertile riparian area results polluted and the palm trees damaged. Taghit is located in sub-Saharan area, near the Moroccan border, the western edge of the Grand Erg Occidental (GEO) (623 m a.s.l.). In the Figures 7 and 8, the main climate characteristics of the oasis are represented.

Although almost 98% of urban wastewater is collected regularly, the main source of pollution is represented by a poor sustainable wastewater management. Currently, wastewater generated from 5 villages located around the oasis Taghit (Zaouia Fougania, Thaghit, Berrabi, Bhakti, Zaoui Tehtania /

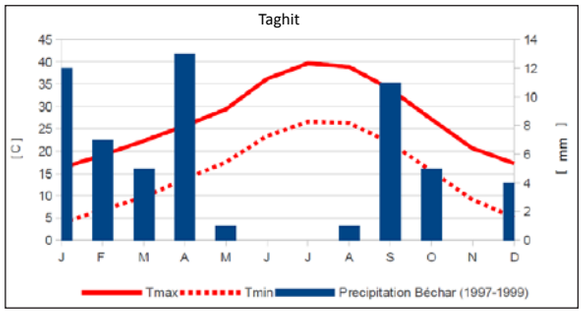

Figure 7 - Taghit (Algeria) – annual average, maximum and minimum temperatures, and annual rainfall distribution.

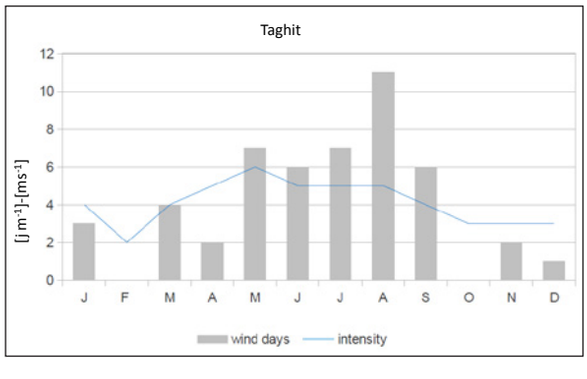

Figure 8 - Taghit (Algeria) – wind regime during the year.

Brika) are released downstream of urban areas and upstream of the palm stands. Final destination of the wastewater stream is the bed of the river Zousfana. Based on qualitative and quantitative characteristics of wastewater produced by each village, constructed wetlands were specifically designed (Fig. 9). After a careful analysis of the characteristics and problems of Taghit Oasis, different possible reuse of the treated wastewater for reforestation and revegetation were also designed, and summarized as follows.

1. Realization of multipurpose irrigated forestry and agroforestry systems

Given the fragility of the oasis ecosystems and climate extremes that characterize them, the fundamental priority is to promote the enhancement of local biodiversity and forest genetic resources (FGR). Indeed, the selection of suitable species for the realization of multifunctional production systems is strongly required. Collection and comparative test of species and provenances is an essential tool for the selection and improvement of forest trees and for starting a process of conservation and management of Forest Genetic Resources. In the specific case of the oasis of Taghit, the implementation of a pilot comparative plantation (species/provenances) was proposed, aiming to assess the variability of the main adaptive traits responsible of the individual adaptability, to sustain the growth and carbon sequestration and to reverse the ecological degradation of fragile ecosystems. Species of high ecological and economic interest (e.g., *Populus alba* L., *P. euphratica* Oliv., etc), will be tested in the experimental plantation (Fig.10).

2. Consolidation of embankment by woody species in order to stop the erosion and to protect the urban infrastructures

Part of the treated wastewater can be used for irrigation of naturalistic engineering works such as: consolidation of embankment, roadsides, riverbanks and landslide slopes. The use of woody species (e.g. *Nerium oleander* L., *Olea europaea var sylvestris* L., *Capparis spinosa* L., *Tamarix* spp.) in such applications allows to increase the effectiveness of anti-erosion and consolidation, reducing water and wind erosion as well as landslides occurrence. Thus, such applications increase the safety of peri-urban and urban infrastructures. In addition to the technical and functional effects mentioned above, works of this kind are also important for other purposes. These bioengineering works, by using native species of the different stages of the dynamic series of potential vegetation, can favour the reconstruction or trigger of the natural potential at the landscape scale. Bioengineering provides cost-effective structures as alternatives (e.g. slope fascines) in respect to traditional structures (e.g. retaining concrete head wall). These are usually more expensive and characterised by higher envi-

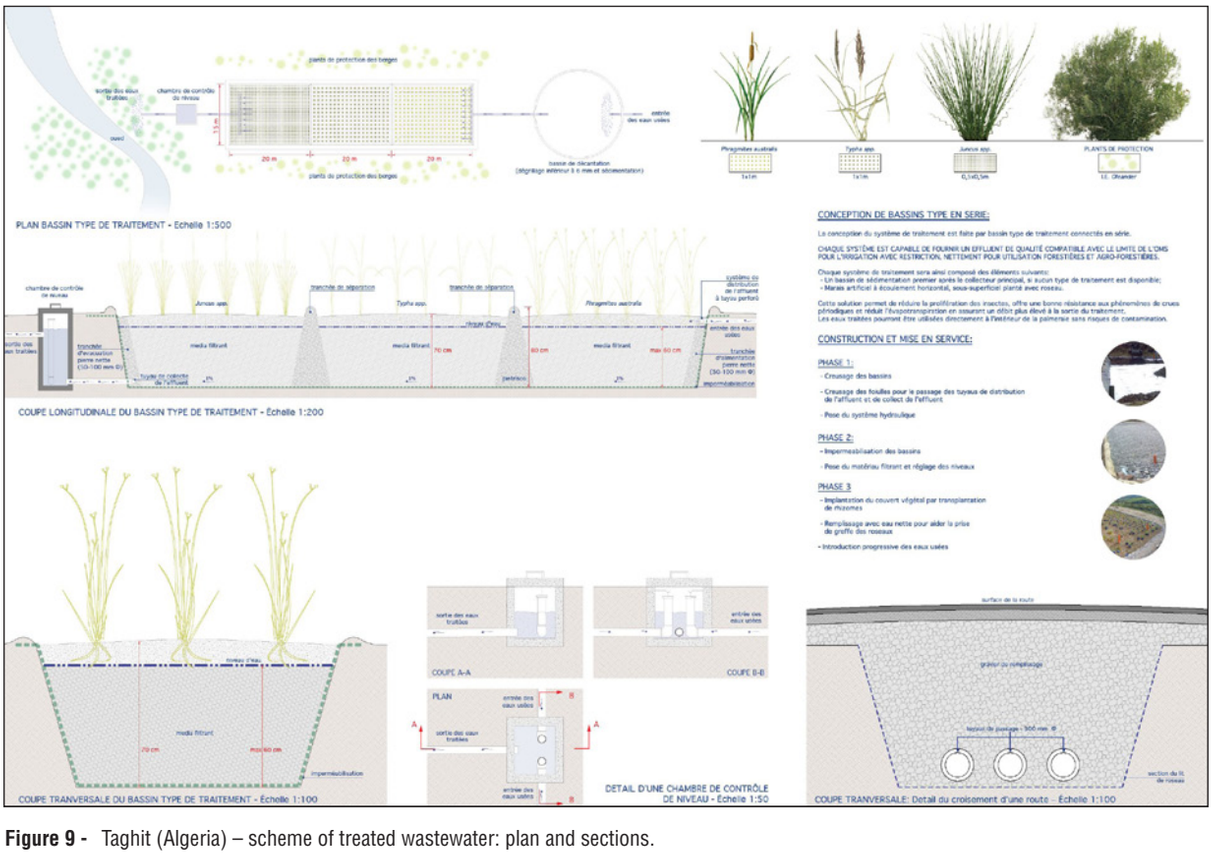

Figure 9 - Taghit (Algeria) – scheme of treated wastewater: plan and sections.

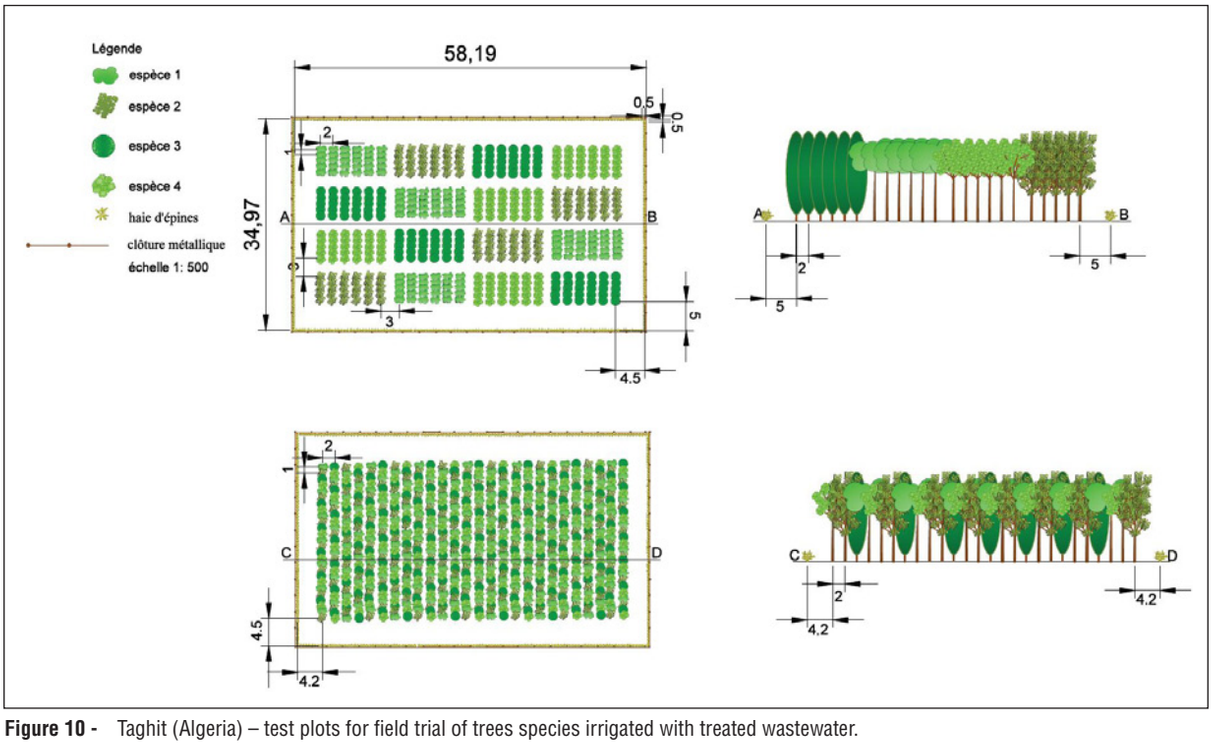

Figure 10 - Taghit (Algeria) – test plots for field trial of trees species irrigated with treated wastewater.

ronmental impacts. Moreover, the green structures provide social and economic incomes and benefits, as their construction and maintenance determine employment, improved environmental quality and environmentally sound management of natural and non-conventional resources (e.g. treated wastewater). Given the degradation and instability of most of road slopes in Taghit, stabilizing interventions were planned, based on the use of local herbaceous plants and shrubs and on rescue irrigations with treated water. In case of superficial instability of the slopes, realization of small steps with wattle fences and fascines was considered.

3. Reducing the environmental impact of the basins of primary treatment (lagoons, settling basins), through the use of vegetated strips of herbaceous species, aromatic shrubs and trees with use of treated waste water for irrigation

The project goal has been the creation of irrigated green belts surrounding the lagoon basin in construction at Taghit (Fig. 11), which are structured as:

A. Buffer zone, formed by herbaceous species (e.g. *Mesembryanthemum* spp.) to limit the damage from possible flooding of the pond caused by extraordinary climatic events and thus reduce the risk of contamination of surface and underground water resources.

B. After a service corridor for the ordinary maintenance of the lagoon basine, a belt of aromatic shrubs (e.g. *Artemisia herba-alba* Turra, *Lavandula antineae* Maire, *Rosmarinus officinalis* L., *Rosa* spp., *Astragalus armatus* Willd., *Helichrysum* spp., *Atriplex halimus* L., etc.) was envisaged with the purpose to reduce the smell air pollution of the primary treatment system.

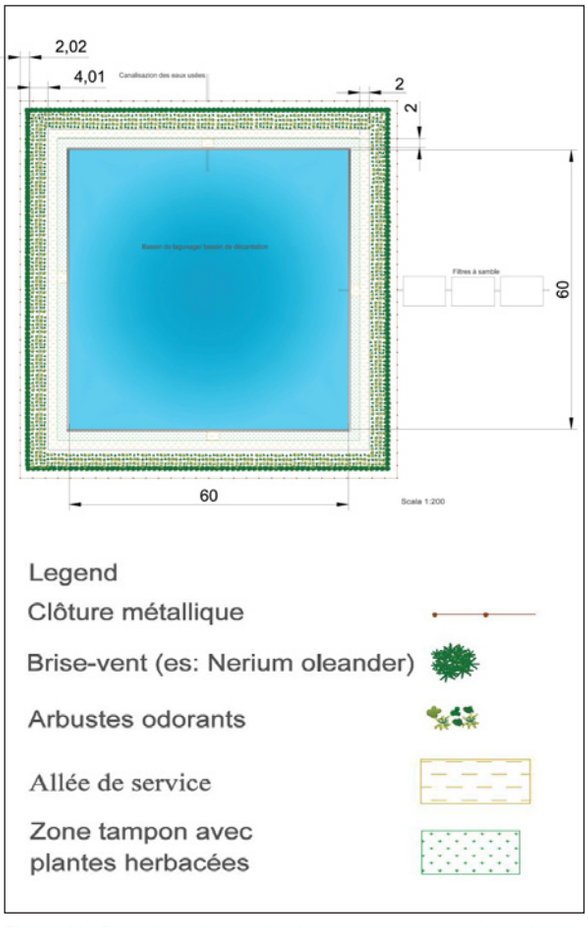

Figure 11 - Plantation of aromatic plants and shrubs to reduce the impacts of the treatment basin.

C. A trees or shrubs windbreak is finally expected (e.g. *Nerium oleander* L., *Tamarix africana* Poir., *Popolus* spp.) that, in addition to the protective function of the lagoon basin to the possible silting effects, will preclude the view from road. The use of species such as N. *oleander* characterized by intense colored blooms, also determines a pleasant visual effect contributing to the aesthetic landscaping, a basic element given the huge tourist interest of Taghit Oasis.

Conclusions

Wastewater harvesting and treatment are required to guarantee a sustainable development of dry lands. Treated urban wastewater is an unconventional but relevant resource, allowing to reserve fresh water uses for more essential needs.

The actual human and economic development produces widespread availability of wastewaters even in areas with scarce surface and ground water. Recycling wastewaters reduces the risk of pollutants seeping into natural habitats and of contaminations of drinking water wells. Such recycle has beneficial environmental effects on soils and water bodies. It can improve carbon storage and water retention in dry soil.

Treated wastewater can be safely used for irrigation of wood plantations, non-food and energy crops. Recycling makes available fresh water resources for the essential needs of people living in dry areas. Moreover, fertigation methodologies, such as those selected for the project, reduce the energy costs of up to 50% compared with traditional systems, allowing the recovery of nutrients to enrich soil fertility.

The use of non-conventional water resources promote reclamation of marginal land, reduction of wind erosion, amelioration of soil conditions, economic stimulation for timber and non-timber products as well as local manpower requirements for new management systems. A new and sustainable agro-forestry management of arid and degraded land is required to guarantee new economic benefits to the local people and to conserve and recover the arid and semiarid lands. The integrated approach proposed in the FAO project can be considered a "*win win*" solution for restoration and conservation of dry lands, mitigation of global climate change and for a sustainable development on the local scale.

In addition, the use of partially treated wastewaters, in forestry and agroforestry activities can provide valid water supply to support the production of timber and firewood, the creation of windbreaks and thus preserve and protect the productivity of agricultural lands. This unconventional resource can contribute to ensure food for local communities, and helps to combat desertification. All this concurs to the achievements of some of "The Millennium Development Goals" established by the United Nations, as the objective 1, 7 and 8 "eradicate poverty and hunger, ensure environmental sustainability, and develop a global partnership for development".

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