Water reuse in Tunisia : stakes and prospects

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Abstract

Water reuse in Tunisia: Stakes and prospects. In the arid and semi-arid region, countries like Tunisia are facing increasingly serious water shortage problems. According to forecasts, increased domestic and industrial water consumption by the year 2020 may cause a decrease in the volume of fresh water available for Tunisian agriculture. It is therefore important to develop additional water resources as well as protect the existing ones. One way to cope with these problems is to reuse wastewater in agriculture. Therefore and before launching the water reuse policy, a research program was undertaken at the beginning of the 1980s. The objectives of the work were to characterize wastewater chemical and biological composition, to establish impacts of wastewater application on the water-soil-plant system, and to evaluate the long-term changes in soil properties connected to irrigation practices. The results showed the feasibility of water reuse provided that some precautions are taken. A national reuse policy has thus been elaborated and implemented, and water reuse was made an essential component of the Tunisian national water resources strategy. Reuse is up to now mainly practiced for crop irrigation and irrigation of recreational facilities, such as golf courses. Other reuse opportunities such as groundwater recharge are screened. In this paper, the water reuse achievements are presented. This is done by reviewing the last decades' research results and the overall reuse framework. Stakes and prospects are also presented.

Résumé

Réutilisation des eaux usées en Tunisie : enjeux et perspectives. Dans les régions arides et semi-arides, des pays tels que la Tunisie font face à des problèmes croissants de déficit en eau. Selon les prévisions, une augmentation de la consommation de l'eau à des fins domestiques et industrielles vers l'an 2020 risque d'entraîner une diminution du volume d'eau disponible pour le secteur agricole. Il est par conséquent important de développer de nouvelles ressources en eau ainsi que de protéger celles qui existent. La réutilisation agricole des eaux usées est un des moyens de faire face à ces problèmes. A cet effet et avant de passer au stade d'une exploitation à grande échelle, un programme de recherche a démarré depuis 1980 sur ce sujet. L'objectif de ce travail était de déterminer les conditions d'utilisation agricole des eaux usées traitées tenant compte de leur composition physico-chimique et biologique, des impacts de l'application d'eaux usées sur le système eau-sol-plante, et d'évaluer les effets à long-terme de leur application sur les propriétés du sol tenant compte des pratiques d'irrigation. Les résultats obtenus ont montré la faisabilité de la réutilisation des eaux usées moyennant des précautions d'emploi. Une politique nationale de réutilisation des eaux usées a ainsi été élaborée et mise en place. La réutilisation des eaux usées est devenue une composante essentielle de la stratégie nationale des ressources en eau. Les eaux usées sont essentiellement utilisées à des fins agricoles et pour l'irrigation d'espaces récréationnels tels que les terrains de golf. D'autres opportunités de réutilisation des eaux usées telles que la recharge de nappes sont à l'étude. Les principaux résultats de recherche obtenus durant les dernières décades, le cadre général de la réutilisation des eaux usées ainsi que les enjeux et les perspectives sont présentés dans ce papier.

Introduction

In the arid and semi-arid region, countries such as Tunisia are facing increasingly more serious water shortage problems. Problems of water scarcity will intensify because of population growth, rise in living standards, and accelerated urbanization which threaten the water supply in general and agriculture in particular and lead to both an increase in water consumption and pollution of water resources. Continuing increase in demand by the urban sector has led to increased utilization of fresh water for domestic purposes, on the one hand, and production of greater volumes of wastewater, on the other. Agriculture in competition with other sectors will face increasing problems of water quantity and quality considering increasingly limited conventional water resources and growing future requirements and a decrease in the volume of fresh water available for agriculture. Around the cities of the region, competition with other sectors often makes water the main factor that limits agricultural development. Policy makers have then been compelled to develop additional water resources as well as to preserve the existing ones. Reclaiming water is among various measures designed to encourage integrated and efficient management and water use was therefore made an important component of the national water resources strategy. To strengthen the development and utilization of reclaimed water, research work was carried out. The main research results related to the agricultural use of reclaimed water are presented in this paper as well as the overall water reuse framework.

Water resources and wastewater characteristics

General

Tunisia extends from the Mediterranean coast in the North to the Sahara desert in the South and its total surface area is 164 150 km^2. The Tunisian coastline extends over 1300 km. Average annual rainfall is around 594 mm in the North, 289 mm in the Centre, and 156 mm in the South. The annual precipitation in Tunisia is on average equal to 37 billion m^3. The annual evaporation varies between 1300 mm in the north to about 2500 mm in the south. The water resources are about 4.7 billion m^3 of which 2.7 billion m^3 are from surface water and 2 billion m^3 from groundwater. The volume of water brought on-line during the terms of the Eighth Economic, Social, and Development Plan (1997) was about 3100 million m^3 (Mm^3), i.e., 66% of the potential water resources, from large dams, hillside-dams, open shallow wells, deep tubewells, and springs. The country's five-year development plans emphasize water reuse and water harvesting. Reclaimed water is now a part of Tunisia's overall water resources balance (Table I) (Bahri, 1998b). It is actually considered as an additional water resource and as a potential source of fertilizing elements (UNDP, 1987a). Water reuse has been made an integral part of overall environmental pollution control and water management strategy. It is also considered as a complementary treatment stage and consequently, as a way of protecting coastal areas, water resources, and sensitive receiving bodies.

Table I. Accessible (A) and available (B) water in Tunisia (Mm^3/yr) for different time-horizons (Ministry of Agriculture, 1998)

	1996		2010		2020		2030	
	A	B	A	B	A	B	A	B
Large dams	1 340	871	1 800	1 170	1 750	1 138	1 750	1 138
Hillside-dams and lakes	65	59	100	50	70	35	50	45
Tubewells and springs	997	997	1250	1 150	1 250	1 000	1 250	1 000
Open wells	720	720	720	720	720	620	720	550
Reclaimed water	120	120	200	200	290	290	340	340
Desalinated water	7	7	10	10	24	24	49	49
Total	3 249	2 774	4 080	3 300	4 104	3 107	4 159	3 122

Wastewater treatment and characteristics

Most residents of large urban centres have access to adequate sanitation systems and the wastewater treatment facilities generally follow conventional designs. The sanitation coverage in the sewered cities is about 78%; this rate, related to the whole urban population (5.8 million), is 61%. Concerning industry, compliance with the Tunisian standards (INNORPI, 1989a) to discharge wastewater into the sewerage system is required. So, preliminary treatment plants to fulfil the discharge requirements stated in the regulations must be implemented. Subsidies are given to equip industrial units with pre-treatment processes.

Of the 240 Mm^3 of wastewater discharged annually, 140 Mm^3 (58%) are treated in 61 treatment plants (WWTP) of which around 41 have a daily capacity less than 3500 m^3 and 10 above 10 000 m^3, Choutrana being the largest with 120 000 m^3/d. Five treatment plants are located in the Tunis area, producing about 62 Mm^3/yr or 54% of the country's treated effluent. Several of the plants are located along the shoreline to protect coastal resorts and prevent sea pollution. Municipal wastewater is mainly domestic (about 88%) and processed biologically up to a secondary treatment stage. The treatment processes vary from plant to plant depending on wastewater origin and on local conditions. Out of 61 treatment plants, 44 are based on activated sludge (medium or low rate), 3 on trickling filters, 14 on facultative or aerated ponds. Sanitation master plans have been designed for several towns. The annual volume of reclaimed water is expected to reach 290 Mm^3 in the year 2020. The expected amount of reclaimed water will then be approximately equal to 18% of the available groundwater resources and could be used to replace groundwater currently being used for irrigation in areas where excessive groundwater mining is causing salt-water intrusion in coastal aquifers.

There are, however, some constraints related to reclaimed water quantity and quality:

- Reclaimed water is consistent with the Tunisian standards regarding water quality required for agricultural reuse (INNORPI, 1989b). However, salinity and the microorganisms content are the two major constraints related to secondary effluent quality. Reclaimed water is often salt-affected (Table II) due to sea- or groundwater seepage into the sewerage network, to the plant location (near a salty lake), and to industrial activities. This salt load limits the range of crops to irrigate and the benefits related to water reuse, and may affect the soil chemical and chemical properties.

Table II. Reclaimed water annual flow and salinity level

EC (µS/cm)	Annual flow (m^3/yr)	%
Slightly saline: 700 – 3 000	14 006 664	12
Medium saline: 3000 - 6 000	92 740 287	80
Highly saline: 6000 - 14 000	9 231 807	8
Total	115 978 758	100

- Tunis concentrates 54% of the country's effluent, which means that large storage infrastructures are needed. On the other hand, peri-urban irrigated areas are mainly devoted to the production of eaten raw vegetables, which is a major constraint to reuse development in the case of crop restrictions. Availability of agricultural land is another limiting factor, especially along seashores. Transfer of water for reuse may then be required even though expensive.

Water reuse implementing approaches

A gradual approach to expanding reuse since the mid 1960s has been adopted (UNDP *et al*., 1992). The strategy has consisted of 1) extending wastewater treatment to all urban areas; 2) conducting pilot- and demonstration-scale irrigation operations on agricultural and green areas; 3) establishing large scale irrigation schemes; and 4) implementing a policy calling for an increase in the percentage of treated effluent that is to be reused. Different development phases can then be distinguished.

First phase : Reclaimed water to safeguard citrus production. Some of the wastewater from Tunis has been used since the early 1960s to irrigate 600 ha of citrus fruit orchards located at La Soukra (8 km North East of Tunis). The reason for using the wastewater was to reduce the impact of salt water intrusion due to excessive pumping of groundwater. The reuse has enabled citrus fruit orchards to be saved. Effluents were thus used, mainly during spring and summer, either exclusively or as a complement to groundwater. Irrigation of vegetables was not allowed.

Second phase : Planned reclaimed water reuse. The water reuse policy was launched at the beginning of the 1980s. The main applications of water reuse are agricultural irrigation, and landscape irrigation. Some pilot projects have been launched or are under study for groundwater recharge, irrigation of forests and highways, and wetlands development. Water reuse was implemented after the construction of existing treatment plants. However, for new plants, treatment and reuse are combined already at the planning stage.

About 35 Mm^3 of reclaimed water is annually allocated for reuse. A total flow of about 28 Mm^3/yr. of treated effluent (approximately 20% of the treated effluent) is being reused. In some areas, irrigation with effluents is well established and most of the volume allocated is being used, while in new areas where irrigation is just beginning, the reclaimed water usage rate is slowly increasing. The area currently equipped is about 6500 ha, 80% of which are located around Tunis. Other projects are being implemented extending the area to 9000 ha. The use of secondary treated effluents in Tunisia is for a restrictive irrigation from which all vegetable crops, whether eaten raw or cooked, are forbidden. The main crops irrigated with treated wastewater are fruit trees (citrus, grapes, olives, peaches, pears, apples, grenades, etc.) (28.5%), fodder (alfalfa, sorghum, berseem, etc.) (45.3%), industrial crops (sugarbeet) (3.8%), and cereals (22.4%). 57% of the equipped area are sprinkler irrigated and 48% surface irrigated. Some farmers use localised irrigation systems. Cattle (milking cows, calves, sheep, and goats), not grazed on pastures irrigated with treated wastewater, is also fed with forage crops cultivated on the irrigated areas.

A water reuse program has been established and experimental research has been conducted on the subject. The institutional and legal framework of water reuse in agriculture has been set up to regulate the treatment and the distribution of irrigation with reclaimed water, to supervise the Water Code and other enactments application and to control the sanitary aspects. Water reuse in agriculture is regulated by the 1975 Water Law and by the 1989 decree (Decree No. 89-1047). In separate documents, reclaimed water quality standards for reuse (INNORPI, NT 106.03, 1989b), wastewater disposal standards in receiving waters (INNORPI, NT 106.002, 1989a), a list of crops that can be irrigated as well as the specifications determining the conditions of reclaimed water reuse have also been set up. The reclaimed water quality criteria for agricultural reuse were developed using the FAO guidelines (Ayers and Westcot, 1985), the WHO guideline (1989) for restricted irrigation (< 1 helminth egg per litre), and other Tunisian standards related to irrigation or water supply. Responsibility from wastewater collection to use in agriculture is shared among various ministries: the Ministry of Agriculture (the National Sewerage and Sanitation Agency, the General Directorate for Agricultural Engineering, the Regional Commissariats for Agricultural Development), the Ministry of Public Health, the Ministry of Tourism and Handicrafts. Users' associations are also involved in water reuse operations.
As municipal wastewater discharges at a more or less constant rate throughout the year and as its volume will increase with urban, tourism, and industry development, wastewater will be reused for agricultural purposes -the area irrigated with treated wastewater is planned to expand up to 20-30 000 ha, i.e. 7-10% of the overall irrigated area, with 14 500 ha located around the Great Tunis- and in other activity sectors. A new wastewater treatment plant is planned for the city of Tunis *The Tunis-West project* with a design capacity in the year 2016 of 105 000 m^3/d (41 Mm^3/yr.). The treatment plant will be operated as a BOT. Interseasonal storage (9 Mm^3 in 2001, 15 Mm^3 in 2016) in hillside dams is included for water resources protection purposes, and increase of the resource. In a first phase, an irrigation scheme covering 1 000 ha is planned. The total irrigated area should cover about 6000 ha. Farmers' willingness to reuse reclaimed water is taken into account. Water users' associations will manage the irrigation system. The water distribution system at the plot level will be optimised and irrigation saving methods will be encouraged.
Third phase : Development of reclaimed water reuse. Actually, there are several other water reuse opportunities when the water quality is in adequacy with the intended end use of the effluent (Asano and Levine, 1996). Diversification of the reuse options by developing non-agricultural uses such as municipal, industrial, and environmental uses is on the way. Based on the on-going reuse projects, a study aimed at developing a strategy to promote water reuse was launched in 1997 (Bechtel and Scet, 1998). The study showed that the strategy should be oriented towards the substitution of conventional water by reclaimed water for the high-rated water activities or the creation of a new demand based on strategic projects. Promotion of reclaimed water reuse should be based on (1) a real water demand, (2) the definition of appropriate water quality standards for the different uses, (3) a relevant regulation, (4) clarified and identified responsibilities for the different interested parties, and (5) an efficient control on all the uses. The legal and institutional framework should be strengthened. Reclaimed water reuse should be more integrated to water resources management. By upgrading the water quality and with more widespread information, reclaimed water reuse should gain wider acceptance in the future. Projects aimed at developing water reuse have been proposed such as the implementation of the water reuse strategies for the Great Tunis and other major cities, groundwater recharge of some coastal aquifers, industrial reuse of reclaimed water, etc. (SERAH, 2002).

Research regarding use of reclaimed water

A research program co-financed by UNDP was undertaken from 1981 to 1987 by the Rural Engineering Research Center (INRGREF actually). The aim was to determine the conditions to use reclaimed water and sewage sludge in agriculture taking into account their composition, soil types, different crops, and sanitary aspects (UNDP, 1987a). The methodology that was adopted is mainly studies of real field conditions. Research is still continuing. A brief review of the results to date is presented here.

Physical-chemical and biological quality of wastewater

Chemical elements, bacteria, and parasitic content of raw and reclaimed water discharged from different wastewater treatment plants and reused in agriculture have been monitored. It was found that the chemical composition of effluents depended on the treatment process employed, the plant location, the proportion of industrial water compared to domestic, the seepage of brackish/sea water into the sewerage network, and finally on the quality of the water supply.

Table III. Average element concentration for effluents (in mg/L)

Parameter	Mean	CV (%)	Range	NT*
pH	7.6	1.7	7.5 - 7.9	6.5 – 8.5
SS	42.5	112.8	15 - 191	30 (a)
COD	173.6	87.9	61 - 640	90 (a)
BOD_5	35.3	52.1	18 - 70	30 (a)
EC (dS/m)	4.1	41.0	2.4 - 8.9	7.0
TDS (g/L)	2.6	41.4	1.5 - 5.6	-
SAR	8.5	44.9	5.1 - 17.6	-
N	42	36.7	27 - 85	-
P	3.6	45.3	1.6 - 6.5	-
K	52	51.2	18 - 120	-

* Tunisian standards (INNORPI, 1989b).

The composition was characterized by a moderate salinity and sodicity for most of the treatment plants (Table III). This means, consequently, soil salinization risks. Alkalinization risks may not be important because of the high concentration of Ca and the elevated electrical conductivity of the effluents. The fertilizing elements concentration was 30.0 mg N/L, 3.6 mg P/L, and 52.0 mg K/L, on average. Reclaimed water had a high variability of the organic parameters which, for N and P, may be a constraint for fertilization purposes, and a low trace elements content (Table IV), far below the expected toxicity thresholds (Bahri, 1998a). The concentration of almost all regulated elements in raw and reclaimed water were below the maximum concentration recommended for agricultural reuse by the Tunisian standards (INNORPI, 1989b) and had a high fertilizing content which may widely exceed the needs of plant growth for nitrogen and potassium. Over-application of nitrogen exceeding requirements for crop growth may present some risks for crops and/or groundwaters.

Table IV. Element concentration for wastewater (mg/L) and sewage sludge (mg/kg)

Parameter	Influent	Effluent	Sewage sludge
pH	7.1 - 7.9	7.5 - 7.9	6.1 - 8.4
EC (a)	3.0 – 10.4	2.4 - 8.9	2.7 - 11.8
B	0.7 - 1.7	0.3 - 1.4	12 - 111
Cd	0.004 - 0.010	0.004 - 0.008	1 - 39
Co	0.012 - 0.041	0.012 - 0.031	11 - 34
Cr	0.010 - 0.109	0.009 - 0.023	33 - 490
Cu	0.040 - 0.160	0.011 - 0.025	44 - 431
Ni	0.027 - 0.051	0.021 - 0.049	12 - 293
Pb	0.050 - 0.347	0.035 - 0.066	57 – 1 580
Zn	0.074 - 0.482	0.023 - 0.063	170 – 1 500

(a): EC is measured as dS/m at 25°C in water or 1:5 extract in sludge.

Average faecal coliforms and streptococci removal (log units) was about 0-2 in biological wastewater treatment plants such as activated sludge, around 1-2 in aerated lagoons, and from 2 to 5 in stabilization ponds (Trad-Raïs, 1992, 1995). The different treatment processes did not result in a complete removal of pathogenic bacteria such as salmonella except effluents from stabilization ponds which were free of these pathogens. Consequently, stabilization ponds, compared to intensive biological treatment systems, may produce a higher bacterial effluent quality (Trad-Raïs, 1989) consistent with WHO guidelines (WHO, 1989). Reclaimed water had a certain parasitic load, which depends on the treatment process. Stabilization pond effluents were free of parasites.

Soil physical properties, chemical composition, and bacterial contamination

Application of reclaimed water on alluvial and sandy-clayey to sandy soils of experimental stations, has led to little modifications of their physical properties: bulk density of the soil surface layer (0-5 cm) was the same whatever the irrigation water quality (reclaimed water or groundwater) was. Irrigation with reclaimed water did not affect the soil trace element content but, on the contrary, it affected the chemical composition of La Soukra clayey-sandy soils (Bahri, 1987). An increase in the electrical conductivity and in the sodium adsorption ratio and a change in the soil solution composition (bicarbonate-calcic → sodium-chloride) were noticed. This increase was, in this case, within the usual range found when using conventional water. Concerning the bacterial level of contamination, no significant effects of reclaimed water application were recorded on the soil over two years. Microorganisms die-off in the soil was shown to be sensitive to factors such as the climate (temperature, insolation, precipitation, and relative humidity), soil texture, and plant canopy (UNDP, 1987a).

Plant growth, yield, chemical composition, water consumption, and bacterial contamination

Tests were conducted during four years on two species, a fodder crop, sorghum (*Sorghum vulgare*) and a vegetable, pepper (*Capsicum annuum*), and were compared to a control irrigated with well water; the first was flood-irrigated, the second was furrow-irrigated. Irrigation with reclaimed water had a favourable effect on the growth of sorghum and led to a significant increase of N, P, and K contents in plant tissues (Rejeb, 1992) with, however, a lower efficiency in the use of these elements compared to mineral fertilizing (Rejeb, 1993). No effect was noticed for pepper. Fertilizing element (N, P, and K) uptake differed with the crop species but remained low compared to the soil residual load entailing nitrate groundwater pollution risks. Concerning trace elements, only Fe and Zn concentrations in sorghum leaves increased significantly without reaching thresholds values; the same was observed for B (Rejeb, 1992). Similar studies were conducted on maize, alfalfa, and barley. The use of reclaimed water compared to irrigation with groundwater resulted in higher annual and perennial crop yields. Recycling of wastewater nutrients can then offer both environmental and economic benefits. In pot experiments, N, P, and K efficiency of reclaimed water was compared to mineral fertilizing (ammonium nitrate). Results showed that global effects of effluents were less important than that of mineral fertilizers; however, compared to a non-fertilized control, wastewater application led to a higher dry matter production. Therefore, irrigation with reclaimed water has to be considered as a complementary fertilization that has to be taken into account when the fertilizer amount to apply is to be evaluated. Water consumption of citrus trees did not depend on the water quality (UNDP, 1987a).

Tests conducted during two years showed that citrus fruits produced on plots irrigated with reclaimed water and not in contact with the soil were free of faecal germs. Contamination level of citrus fruits picked up on the soil of plots irrigated with reclaimed water was significantly higher than that of fruits picked from the trees (UNDP, 1987a). As to annual crops, experiments were made first to evaluate the bacterial quality of fodder crops irrigated with effluents and to compare them to non-irrigated fodder crops (winter crops) or to fodder irrigated with groundwater (Trad-Raïs, 1991). Results showed that faecal contamination of forage crops sampled from control plots was not equal to zero. This contamination, due to natural factors, was higher for summer forage crops. Bacterial quality of forage crops irrigated with reclaimed water depended on the crop specie, the number of days since the last irrigation occurred and the climatic conditions. For both sorghum and alfalfa, 7 to 10 days were required between the last irrigation and the cutting to achieve natural decontamination. The natural die-off of faecal microorganisms on sorghum plants was quicker in summer than in autumn. As to pepper, tests did not show any particular fruit contamination.

Chemical and bacterial groundwater composition

Besides reclaimed water reuse for agricultural purposes, seasonal recharge of the shallow and sandy aquifer of Nabeul has been performed since 1985. Activated sludge effluents that were not used for irrigation during winter season were infiltrated and stored into the aquifer, thus increasing the volume farmers can pump during summer season to irrigate citrus orchards. Artificial groundwater recharge is operated at experimental scale in infiltration-percolation basins and in the riverbed in the Cap Bon area. Groundwater recharge efficiency was proven not only by the increase of the water level in the wells but also by the improvement of the production of the surrounding wells. This experiment allowed an underground storage and an additional treatment step as wastewater slowly infiltrated through the unsaturated zone (7 months after the end of the recharge, nitrogen concentrations were about few milligrams per litre) through the unsaturated zone (UNDP, 1987b). However, no clear conclusion could be drawn about the effect of reclaimed water on the bacterial and chemical composition of shallow groundwater since the initial contamination level of most of the wells was relatively high and subject to seasonal variations. According to the *state of the art* of soil-aquifer treatment (Bouwer, 1991; Brissaud and Salgot, 1994), improved operation of this facility would lead to a groundwater quality meeting unrestricted irrigation requirement (Rekaya and Brissaud, 1991). Performing coastal aquifer recharge, where the hydrogeological context is favourable, would make water reuse well accepted by farmers. This subject is still under study and other sites are screened for further studies including the comparison of different treatment processes preceding recharge.

Recreational reuse

Since the beginning of the 1970s and with the development of tourism, a policy was set up for golf course irrigation with reclaimed water. Golf course irrigation means a high rate of water reuse and a water demand that lasts all the year long through varying climatic conditions. Actually, the eight existing golf courses are irrigated with secondary-treated effluent. Some are irrigated with reclaimed water blended with conventional water (surface or ground-water). Irrigation water is in compliance with the WHO guidelines (1989) for water reuse on recreational areas with free access to the public (2.3 log. units /100 mL) during winter and part of spring (Bahri *et al*., 2001). Polishing secondary effluents through lagooning or seasonal storage would lower health hazards and contribute to increase this demand of reclaimed water (Bahri *et al*., 2000). Supplying reclaimed water to golf courses, green belts, and hotel gardens would result in an optimization of both investment and operation costs.

Long-term effects

Investigations in La Soukra's perimeter, which has been irrigated for more than twenty years with reclaimed water have been conducted. The results did not show notable effects on soils, crops, or groundwater. A study conducted in this scheme to evaluate health impacts of reclaimed water reuse could not set up a clear cause-effect relationship between the observed diseases and the reuse practice.

Research needs

Additional scientific work is needed to reduce persistent uncertainty about the potential impacts on human health and the environment from exposure to reclaimed water. A number of knowledge gaps are identified in the following:

- Improvement of existing treatment processes and appropriate selection/combination of treatment methods.
- Development of cost-effective and innovative wastewater treatment technologies, especially energy-saving and reliable processes (biotechnologies for degradation of refractory organics, etc.).
- Disinfection treatment processes.
- Storage systems: planning, operation, improvement of reclaimed water quality.
- Achieving best use of nutrients without adverse impacts such as over-fertilization problems and groundwater pollution.
- Fate of microorganisms and contaminants (refractory trace organics, pharmaceutically active chemicals, etc.) in the water-soil-plant system and evaluation of the soil's absorptive capacity to assimilate, and detoxify pollutants in agricultural and groundwater recharge applications.
- Improvement of irrigation systems (filtration, distribution (localized, etc.), etc.).
- Long-term effects of reclaimed water reuse on the soil-plant-aquifer system.
- Risk assessment studies on water-soil-plant-animal-human exposure pathways.
  Decentralized management of wastewater treatment and reuse for small communities.
  Assessment of the reclaimed water market and screening other reuse opportunities: groundwater recharge, municipal, industrial uses, etc.
  Evaluation of the socio-economic feasibility of reclaimed water reuse.

Conclusion

During the last decades, Tunisia has gained experience in the field of irrigation with emphasis on the use of marginal water for agricultural crops. To try on a rational basis to make a better use of the water resources on account of their rather limited quantity, research should continue along some of the lines already carried out with a broadening of it with emphasis on socio-economic aspects. This also requires a strengthening of the human potential of researchers, material means, and integrated multidisciplinary efforts.

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