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Waste Water Treatment and Reuse in the Mediterranean Region

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Waste Water Treatment and Reuse in the Mediterranean Region

Volume Editors: Damià Barceló · Mira Petrovic

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Aims and Scope

Since 1980, *The Handbook of Environmental Chemistry* has provided sound and solid knowledge about environmental topics from a chemical perspective. Presenting a wide spectrum of viewpoints and approaches, the series now covers topics such as local and global changes of natural environment and climate; anthropogenic impact on the environment; water, air and soil pollution; remediation and waste characterization; environmental contaminants; biogeochemistry; geo-ecology; chemical reactions and processes; chemical and biological transformations as well as physical transport of chemicals in the environment; or environmental modeling. A particular focus of the series lies on methodological advances in environmental analytical chemistry.

Series Preface

With remarkable vision, Prof. Otto Hutzinger initiated *The Handbook of Environmental Chemistry* in 1980 and became the founding Editor-in-Chief. At that time, environmental chemistry was an emerging field, aiming at a complete description of the Earth's environment, encompassing the physical, chemical, biological, and geological transformations of chemical substances occurring on a local as well as a global scale. Environmental chemistry was intended to provide an account of the impact of man's activities on the natural environment by describing observed changes.

While a considerable amount of knowledge has been accumulated over the last three decades, as reflected in the more than 70 volumes of *The Handbook of Environmental Chemistry,* there are still many scientific and policy challenges ahead due to the complexity and interdisciplinary nature of the field. The series will therefore continue to provide compilations of current knowledge. Contributions are written by leading experts with practical experience in their fields. *The Handbook of Environmental Chemistry* grows with the increases in our scientific understanding, and provides a valuable source not only for scientists but also for environmental managers and decision-makers. Today, the series covers a broad range of environmental topics from a chemical perspective, including methodological advances in environmental analytical chemistry.

In recent years, there has been a growing tendency to include subject matter of societal relevance in the broad view of environmental chemistry. Topics include life cycle analysis, environmental management, sustainable development, and socio-economic, legal and even political problems, among others. While these topics are of great importance for the development and acceptance of *The Handbook of Environmental Chemistry,* the publisher and Editors-in-Chief have decided to keep the handbook essentially a source of information on "hard sciences" with a particular emphasis on chemistry, but also covering biology, geology, hydrology and engineering as applied to environmental sciences.

The volumes of the series are written at an advanced level, addressing the needs of both researchers and graduate students, as well as of people outside the field of "pure" chemistry, including those in industry, business, government, research establishments, and public interest groups. It would be very satisfying to see these volumes used as a basis for graduate courses in environmental chemistry. With its high standards of scientific quality and clarity, *The Handbook of*

Environmental Chemistry provides a solid basis from which scientists can share their knowledge on the different aspects of environmental problems, presenting a wide spectrum of viewpoints and approaches.

The Handbook of Environmental Chemistry is available both in print and online via www.springerlink.com/content/110354/. Articles are published online as soon as they have been approved for publication. Authors, Volume Editors and Editors-in-Chief are rewarded by the broad acceptance of *The Handbook of Environmental Chemistry* by the scientific community, from whom suggestions for new topics to the Editors-in-Chief are always very welcome.

Damià Barceló
Andrey G. Kostianoy
Editors-in-Chief

Volume Preface

Scarcity of water resources and needs for protecting the environment and the natural resources are the main factors leading the Mediterranean countries to introduce treated wastewater as additional water resources in the national plan of water resource management. The need to introduce remediation and treatment technologies in the water cycle was also recognized by the European Commission, and several projects have been funded aiming at "improving WW treatment" and "minimizing environmental effects of WW treatments". This book summarizes developments and results achieved within the project **INNOVA-MED** "Innovative processes and practices for wastewater treatment and re-use in the Mediterranean region" that was funded under the 6th Framework Programme with the main objective of exploring the synergies of the research carried out within different programmes and countries and dealing with the development of innovative technologies for wastewater treatment and application of innovative practices for reuse of reclaimed water. The aim of Coordination Action **INNOVA-MED** was to facilitate the communication between researchers and national and/or regional institutions from the Mediterranean Partner Countries (MPC), and we hope that this book also represents one step forward in a broad dissemination and transfer of the knowledge/technology/practice to the Mediterranean area.

The book is structured into two main parts, covering a wide range of topics related to the *Waste Water Treatment and Reuse in the Mediterranean Region*:

- The first part (Chaps. 1–7) brings a general overview of innovative technologies and practices for wastewater treatment and reuse in the Mediterranean region.
- The second part (Chaps. 8–11) brings several practical examples of Mediterranean countries experiences on the application of innovative processes and practices for wastewater treatment and reuse. Examples from several Mediterranean countries such as Tunisia, Egypt, Morocco, Palestine, and Spain are included.

We hope the book will be of interest to a broad audience of environmental chemists, water managers, operators, and technologists working in the field.

Finally, we would like to thank all the contributing authors of this book for their time and effort in preparing this comprehensive compilation of research papers.

Barcelona, November 2010

Damià Barceló
Mira Petrovic

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Technologies for Advanced Wastewater Treatment in the Mediterranean Region

Sixto Malato, Isabel Oller, Pilar Fernández-Ibáñez, and Maria Fuerhacker

Abstract Research in and application of advanced wastewater treatment technologies in the Mediterranean Basin require public awareness of the need for sustainable water resources to be raised through local information programs. Since wastewater treatment and reuse systems are generally capital-intensive and require highly-paid specialized operators, this point must be given especial relevance when applying new techniques, such as membrane bioreactors, tertiary chemical oxidation processes, etc., in these countries. This chapter gives a general overview on research currently underway in the Mediterranean Basin countries on innovative technologies for wastewater treatment, and compares them to the conventional technologies currently employed in wastewater treatment plants. Moreover, not only water availability, but also water quality, is essential for human life, health and safety, especially if sanitary requirements are not met. A summary of disinfection applications and research activities under development in the South Mediterranean and Middle East Regions is presented.

Keywords Advanced oxidation technologies, Photocatalysis, Solar disinfection, Tertiary treatment

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1 Introduction

In developing and developed countries, rapid urbanization and the consequent growing demand for potable-useable and industrial water is necessitating costly, large-scale projects. This shortage of fresh water constitutes a severe problem in the Mediterranean Region and particularly in the arid and semi-arid areas to the South and in the Middle East, and is giving rise to serious parallel problems of effluents, which are treated with more or less success depending on the ability to develop effective, rational and affordable sewage strategies. However, water treatment is expensive and requires heavy financing. In view of the above, it is clear that not only efficient water management, but extensive research, education and consumer awareness programs are all of vital importance.

An analysis of industrial water consumption reveals the difficulty of making an overall assessment in a field where data are highly fragmented and scarce, as reflected in both international sources and the respective national services, often resulting in an absence of data surveys on specific parameters, sector studies, or industrial classifications. The trend for an increasing need of water is clear, especially in developing Mediterranean countries where industry has had enormous impact on the economy in the last few decades. In Tunisia, for example, the yearly water demand has been increasing with the growth of business by about 1.9% in recent years.

Almost all countries identify the most critical part of industrial water use with its pollution. Most threats of pollution come from oil extraction and refinery waste, heavy metals, heat and by-products. Therefore, industrial growth is bound to impact heavily on water quality, with potentially harmful follow-up on human health and posing severe social concerns. This impact could be enhanced by the overlapping effects of industry, urbanization and tourism, and the situation will predictably worsen if nothing is done about it.

This chapter includes an overview of innovative technologies for wastewater treatment – Membrane technology (MBR, nanofiltration, reverse osmosis); Advanced oxidation or reduction technologies (mainly catalytic or photocatalytic); Advanced bioactive technologies (aerobic or anaerobic); and new solutions such as electrolysis/electrodialysis, electron beam irradiation, electromagnetic treatment, etc. – and a proposal for solutions to current problems or a friendlier alternative to present treatments in Mediterranean Basin Countries. It also contains a brief summary of existing industrial wastewater treatment technologies. Finally, considering the significance of disinfection applications for human health and hygiene, a review of disinfection of wastewater treatment plant (WWTP) effluents for water reuse in the Southern Mediterranean and Middle East Regions has also been included.

2 Research and Development of Innovative Technologies for Industrial Wastewater Treatment in the Mediterranean Region

It is estimated that in 1990, approximately 280 km^3 of water were consumed in the Mediterranean Region, including riparian countries and those bordering the Mediterranean Sea, of which 99% came from natural resources. The demand doubled in the twentieth century, and increased by 60% in the last 25 years. In recent decades, per capita water demand has developed differently in different countries, depending on the conditions of demographic growth and economic development. By the year 2025, practically no Southern Mediterranean country will have resources over an average of 500 m^3 per capita/per year which clearly shows an increasingly acute problem [1].

Conventional technology, particularly in terms of performance and available wastewater treatment options, cannot be expected to find a solution to all of the problems. Wastewater systems are generally capital-intensive and require expensive, specialized operators. Therefore, before selecting and studying a given wastewater treatment technology, cost effectiveness should be analyzed and all conceivable alternatives compared. The selection of technologies should be environmentally sustainable, appropriate to local conditions, acceptable to users, and affordable for those who have to pay for them. Simple, easily replicated solutions, allowing further upgrading with later development which can be operated and maintained by the local community are the most appropriate and cost effective. The choice of technology depends on the type of wastewater.

In developing countries, usually characterized by high population densities and a noticeable shortage of available water, the best wastewater technology to use under the prevailing local conditions is one of the critical issues which should be well defined.

Nevertheless, the quality of the effluent is not only defined by prevention of eutrophication as it is in the EU Urban Waste Water treatment Directive (UWWTD), but for irrigation reuse purposes the requirements of WHO (2006) standards for restricted and unrestricted use must also be considered. Any treatment or reuse system should be designed according to national and/or international regulations, specifications, standards, and guidelines on wastewater collection, wastewater flow and effluent quality, and solve environmental and health problems. The technologies applied should remove a majority of pathogens. A secondary treatment (i.e., removal of settleable and suspended solids and biodegradable organics plus disinfection) is usually the minimum acceptable treatment level. The new concept for microbial safety of drinking water and wastewater (Quantitative Microbial Risk Assessment) requires quantitative data on the inactivation or removal of pathogenic microorganisms by water treatment processes.

For the local application of treatment techniques, studies undertaken must include detailed microbiological, chemical and biological risk assessment factors to identify necessary technologies, uses and control tools. For regional utilities, this minimum treatment level is expanded to include tertiary treatment. Rules and regulations need to be established for that, or adjusted to the new WHO (2006) requirements. Growers, who might benefit from wastewater or sludge reuse, should be involved in the project, as appropriately treated wastewater is a valuable resource that must be used to best advantage, and agriculture is given priority for water reuse.

Lack of personnel with the appropriate technical and managerial skills for the use of advanced technological tools and implementation of modern management strategies are among the major constraints for attaining more efficient wastewater management practices. There is a general need to transform the concepts of water efficiency improvement and water saving in industrial applications into ground-level implementation policies, programs and actions in countries particularly affected by water shortage problems, such as the arid and semiarid areas in the South Mediterranean and Middle East.

Many well known technologies are available, but it has been widely demonstrated that certain kinds of industrial wastewater require the application of innovative treatment technologies [2]. Moreover, any choice should not entail heavy costs and provide the best environmental practice. Accordingly, several research projects on new wastewater treatment processes applied to typical industrial effluents have been carried out in the Mediterranean Basin countries during the last 6 years. In this context, representative case studies carried out in Turkey, Tunisia, Egypt, Morocco, and Palestine are described below.

2.1 Research on Innovative Wastewater Treatment Technologies in Turkey

Industrial water consumption in Turkey was 4,100 million m^3 in 2000 (10% of the total). In 2003, water consumption in industry was calculated at 4.3 billion m^3, and the forecast for 2030 is 22 billion m^3 (Table 1) [3].

Turkish industry has been mainly private since the public share has been decreased through privatization in recent years. Over 80% of production and about 95% of gross fixed investment in manufacturing is currently private.

Table 1 Total water consumption in Turkey

	In 2003 (billion m^3)	In 2030 (billion m^3)
Irrigation	29.6	72.0
Drinking water	6.2	18.0
Industry	4.3	22.0
Total	40.1	112.0

75% of Turkey's industrial wastewater is discharged without any treatment, primarily into seas and rivers, 20% receives adequate treatment, and 5% receives only primary treatment. Moreover, approximately half of the 190,000 industrial enterprises in Turkey work in pollution-creating industries [4].

Furthermore, in Turkey:

– Only 9% of industry has WWTPs.
– 84% of businesses lacking WWTPs are government-owned and the rest are private.
– Only 14% of industrial zones have treatment systems.
– 81% of touristic facilities have treatment systems.
– There are 3,215 municipalities of which only 141 have sewage systems and only 43 have treatment plants. In other words, 98.7% of domestic wastewater is discharged into seas, rivers, and lakes without treatment.
– Only 22% of industrial wastewater containing poisoning heavy metals is treated and the rest is discharged into seas, rivers, and lakes without treatment.

Turkish industry is expected to produce in compliance with environmental standards, apply strategic management techniques, make R&D a priority concern, generate technology and create original designs and trademarks, thus taking its place in international markets. This would increase use of advanced technologies in industry, and enhance the competitiveness of traditional industries.

National Five-Year Development Plans (FYDP) are aimed at ensuring optimum distribution of resources among the various sectors of the economy. Under the eighth FYDP (2001–2005), one of the most important policies was to adopt the EU standards for water, wastewater, and solid waste management. The Turkish Law of the Environment (No. 2872, 1983) is based on the principle of the "polluter pays" and deals with the issue of environment in a very broad scope. The law considers the environment as a whole, and aims not only to prevent and eliminate environmental pollution, but also to allow for the management of natural and historical resources and land in a way that allows such richness to be used while conserving it for future generations as well [5].

In an endeavor to achieve successful wastewater management, Turkish researchers in recent years have studied new treatment technologies for highly polluted industrial wastewater.

Most of the research papers recently published deal with the application of advanced remediation processes for different types of textile effluents to alleviate their toxicity and recalcitrance at source. Some authors have simulated these effluents, which contain a nonionic surfactant, synthetic tannin, and an aqueous biocide solution, at different stages of the process to study their treatment with several different AOPs, including ozonization at varying pH and advanced oxidation with H_2O_2/UV-C at varying H_2O_2 concentrations. In all the experiments, detoxification and/or biodegradability improvement was achieved, but were accompanied by high electricity requirements [6]. Other AOPs, such as Fenton´s reagent, $O_3/OH^{•}$ and O_3/H_2O_2 have been also tested for the treatment of effluents from a textile dyeing mill which processes mainly wool and wool blends, yarn and fabric [7]. Leather tanning wastewater taken from the equalization basin outlet of the common treatment plant in an organized industrial tanning region in Istanbul was experimentally treated by an electro-Fenton process [8]. The results showed that wastewater from industrial tanning could be treated and remediated to the local sewage system discharge limit (800 mg COD/L). With respect to traditional oxidation methods and "phase transfer" treatment systems, the combined Fenton oxidation and Fenton coagulation, as well as H_2O_2-enhanced ozonation processes could be regarded as efficient, economically feasible and environmental friendly alternative. Nevertheless, research activities have been also focused on technical evaluation and comparison of different membrane-based treatments, for example, the recovery of dye-house effluents from a carpet manufacturing plant, which represent a significant sub-sector of textile industry in Turkey [9]. In this study, comparison of permeate qualities and diminished flux revealed that wastewater from print and beck-dyeing can be treated together with sufficient quality for reuse in a single nanofiltration (NF) unit even when mixed at equal volumes. Other textile effluents have also been treated by membrane systems; in particular, four alternative membrane process trains were tested for the pre-treatment of acid dye-bath wastewater: single microfiltration (MF), sequential MF, single ultrafiltration (UF), and MF followed by UF. It was observed that single stage processes were as effective as sequential; hence, there was no advantage in implementing sequential filtration [10]. Finally, studies on integrated photochemical (H_2O_2/UV-C) and biological treatment systems have been carried out mainly to demonstrate that the national discharge requirements being set for the textile dyeing and finishing industry can only be achieved by applying integrated chemical/biological treatment [11].

Olive mill wastewater (OMW) represents a major pollutant in many of the Mediterranean Basin countries (including Turkey) due to its high organic load and phytotoxic and antibacterial phenolic compounds which resist biological degradation. Many methods are used for OMW treatment, such as adsorption, electrocoagulation, electro-oxidation, chemical coagulation, flocculation, filtration, evaporation lagoons and burning, etc. Nevertheless, there is no easy, economical solution nowadays. Several studies have therefore focused on developing an advanced oxidation technology for improving treatment of this industrial effluent. On one hand, the Fenton process has been applied after acid cracking and cationic polyelectrolyte pre-treatment, increasing COD removal up to 89% from 74% (without Fenton post-treatment) [12]. The Fenton reaction has also been employed by other researchers [13] to enhance anaerobic biodegradation of OMW by increasing biodegradability of the real effluent almost 3.5-fold. Another widely used AOP is H_2O_2/UV, not only with mercury lamps, but also natural sunlight [14]. In these studies, the authors concluded that in general, color, lignin, total organic carbon and phenol were removed more efficiently using H_2O_2/UV (10 mL H_2O_2/100 mL OMW) and lime (pH up to 7) after a seven-day treatment.

The pharmaceutical industry wastewater also poses a problem for water pollution control due to the complexity, characteristics and variability of the source pollutants. Some research has been done in the way of biological treatability and pre-treatment by ozone oxidation with or without catalyst assistance [15]. For instance, a penicillin formulation effluent containing the active substances penicillin Amoxiciline Trihydrate and the b-lactamase inhibitor Potassium Clavulanate was subjected to ozonation and perozonation, and afterwards a biological activated sludge treatment using a consortium of acclimated microorganisms [16].

In other cases, the new technological development was directed at the biological stage of the treatment with new biological reactor configurations as, for example, a rotating brush biofilm reactor [17].

In general, these studies emphasize that depending on the scope of oxidative treatment (final discharge to a water body or pre-treatment prior to biological activated sludge process), an integrated approach to evaluation considering several parameters, such as the parent pollutant, toxicity and biodegradability, is helpful to provide information about the fate and toxic/inhibitory effects of industrial recalcitrant chemicals in effluent streams and to understand their reaction mechanisms.

2.2 Research on Innovative Wastewater Treatment Technologies in Tunisia

The Tunisian economy strongly depends on its industrial sector, which contributes heavily to economic and social indicators. For the last three decades, manufacturing industries have been the most dynamic component of the production sector. Investments in this sector have gone from 513 million Dinars in 1992 to 1,064 million Dinars in 2001. In 2001, the contribution of manufacturing industries was 89% of total exports.

In view of those figures, it can easily be assumed that industry is a significant consumer of water in Tunisia (Table 2). Although it currently uses less water than agriculture, its need increases with the number of businesses. Irrigation constitutes the largest consumer of water in Tunisia, using 80% of the total water potential in the country.

Table 2 Water demand (million m^3) of different activities in Tunisia

Sector	1996	2010	2020	2030
Drinking water	290	381	438	491
Industry	104	136	164	203
Tourism	19	31	36	41
Irrigation	2,115	2,141	2,083	2,035
Total	2,528	2,689	2,721	2,760

The volume of water used for irrigation is estimated at 2,100 million m^3, with an average per-hectare consumption of approximately 5,500 m^3/year. Consumption reaches 20,000 m^3/hectare/year in the oasis in the South and is on average about 4,000 m^3/hectare/year in the North. The amount of irrigated land is expected to reach 400,000 hectares in 2010. 55% of total agricultural production and 25% of export crops depend on irrigation on only 7% of usable agricultural land [18].

The fast developing Tunisian industry exerts some pressure on the environment and appears to be mainly responsible for water, air, and soil pollution. At the present time, most processes generate polluted wastewater containing all by-products and lost raw materials that cannot be recovered or recycled. The nature and the composition of these wastewaters vary from an industry to another.

It should be emphasized that Tunisian agrofood industries contribute a significant 5555.8 tons to industrial water pollution, close to 47% of the DBO, although it has only a less important 2.19% share of suspended materials. The wood, furniture and paper industry ranks second in pollution with 39.45% of the DBO and 22.33% of suspended materials. The most important contribution to suspended materials is from metal and metallurgy, which is over half: 52.33%.

The Tunisian "Code des Eaux," promulgated in 1975, constitutes the legislative basis governing all intervention in the water sector. The Ministry of Agriculture, Environment and Water Resources is responsible for application of water laws, scheduling, main hydro-agricultural services, and development of management strategies.

Taking into account the highly polluting effects of industrial wastewater, especially from the agrofood industry, several recent studies have been published by Tunisian researchers in the field of testing and developing new treatment technologies. Specifically, many of these studies have concentrated on the remediation of OMW by means of catalytic wet-air oxidation [19]. For instance, fifty-day, long-term catalyzed wet air oxidation of representative phenolic OMW pollutants (p-coumaric acid, p-hydroxybenzoic acid) was conducted using ruthenium catalysts supported on TiO_2 or ZnO_2 in a stirred batch autoclave and in a fixed bed reactor at 140°C, 50 bar air [20]. An extension of this study was the application of a wet peroxide catalytic oxidation process using UV light for the treatment of low molecular phenolic contaminants present in OMW such as hydroxytyrosol, tyrosol, p-hydroxyphenhylacetic acid, vanillic acid, p-coumaric acid, ferulic acid, caffeic acid, and p-hydroxybenzoic acid [21]. The photocatalytic treatment decreased toxicity to 74% of luminescence inhibition and a subsequent biological treatment using a methanogenic consortium removed over 70% of the remaining phenolic compounds.

2.3 Research on Innovative Wastewater Treatment Technologies in Egypt

About 350 industries located along the Nile may cause pollution risk to the Nile Water. Chemicals, food, metal, and textiles are the most important industries in

Egypt. Industrial discharges to surface or ground water may pose a major threat to agricultural lands. In Egypt, the food industry uses the largest volumes of water.

There are an estimated 24,000 industrial enterprises in Egypt, about 700 of which have major industrial facilities. In general, the majority of heavy industry is concentrated in Greater Cairo and Alexandria. Industrial demand for water in the year 2000 was reported to be 3.6 billion m^3/year, and is expected to reach 5.5 billion m^3/year by 2017, with the corresponding increase in the volume of industrial wastewater.

Egyptian industry uses 638 million m^3/year of water, of which 549 million are discharged into the drainage system. The Nile River supplies 65% of the industrial water needs and receives more than 57% of its effluents.

Industrial wastewater, as part of the wastewater generated in urban areas, is often mixed with domestic wastewater in sewers or directly discharged into the Delta without pre-treatment. Untreated industrial wastewater destroys normal operation of biological treatment processes.

Several studies have revealed that untreated industrial waste, some of which included hazardous chemicals, such as detergents, heavy metals and pesticides, from over 350 factories used to be discharged directly into rivers and water bodies. Textile mills, representing 48.3% of the total number of industrial plants, are responsible for the heaviest organic load (almost 52%). Out of 1,243 industrial plants, 57 have been identified as major sources of marine pollution either directly or indirectly via Lake Marriot. The paper, textile and food industries contribute 79% of the total organic load. As might be expected, average mid-stream Nile conditions are still fairly clean due to dilution and degradation of the pollutants discharged. The riverbanks further downstream, however, are at more risk of pollution.

There are three main regulations governing the discharge of industrial wastewater to the receiving environment. Decree 44/2000, recently issued by the Ministry of Housing, Utilities and Urban Communities (MHUUC), sets quality standards for industrial and commercial wastewater discharge into public sanitary sewers. The Egyptian Environmental Affairs Agency (EEAA) has started several education programs for a Compliance Action Plan (CAP) in the region, although efforts are minor and insufficient.

On the other hand, and taking sanitation into account, it is important to mention that although nearly 98% of the Egyptian population have access to piped water, only 58% have proper sanitation facilities, as not much attention has been paid to effective safe disposal of sewage, especially in rural areas (deserts and agricultural areas). Indeed, a recent report of Water Aid (The State of the World's Toilet 2007) ranks Egypt in 16th worst place in the world sanitation table.

The heavy use of water in food industries made Egyptian researchers focus on the development of new technologies for treatment of their wastewater effluents. In a specific case study, nanofiltration and reverse osmosis membrane separation techniques were used to pre-treat effluents from a food company in Egypt for reuse of the water [22]. The wastewater was pre-treated by flocculation and coagulation. A preliminary technical and economic evaluation of a 1,200-m^3/day treatment plant found a fixed capital cost of 1.46 million Egyptian pounds, and the cost of treating 1 m^3 was 1.3.E.P (1US$ dollar = 5.75 E.P.). The plant designed consists of a holding tank, an oil separator, a flash mixer, a coagulation unit, a clarification and a settling unit, an MAF unit, an MIF unit, a UF unit, an NF unit, and an RO unit.

An important subject of research in this region has also been agricultural wastewater treatment. It is well known that large-scale desalination systems for agricultural drainage water require the development of affordable pre-treatment for removal of soluble organic matter, which includes agrochemical residues and industrial pollutants. In 2002, a preliminary design for an integrated agricultural drainage water treatment for reuse for non-agricultural purposes was presented [23]. The 30,000-m^3/day plant capacity system essentially comprised an aerated lagoon (for the removal of organic matter), a filtration stage and two reverse osmosis or electrodialysis units. The cost of water produced was about US\$0.33/m^3. Recent studies present the technical and economic aspects of treatment and reuse of polluted surface water resulting from mixing river water with agricultural drainage water [24]. Three integrated treatments which cope with seasonal variations of agricultural drainage water were proposed. First of all, an integrated biological/membrane separation where the biologically treated wastewater is further processed by a triple sand, carbon and nano filtration assembly (the use of reverse osmosis was optional for high concentrations of dissolved solids). This is followed by a complementary membrane separation treatment comprised of chemical precipitation and biological filtration. This design is suitable in locations where land is scarce and salinity of agricultural drainage wastewater is low. And finally, a design consisting of slow sand filtration, activated carbon adsorption and an ion exchange separator, useful for wastewater with low BOD and significant concentrations of heavy metals. In this sense, a different integrated treatment system has also been applied to very biorecalcitrant wastewater from the "HELB" Pesticides and Chemical Company in New Dammata in northern Egypt [25]. Photo-Fenton was explored as a photochemical pre-treatment to improve the biodegradability of such wastewater. The results of this study revealed that the final treated effluent complied with the environmental regulations stipulated by Law No. 93/1962 and Ministry of Housing Decree No. 44/2000.

The general practice of mixed industrial and domestic wastewater treatment by chemical processes in the pre-treatment of the combined industrial wastewater (end-of-pipe) generated from textile, chemical, food, and metal-finishing industries and domestic wastewater has been evaluated [26]. In this study, the Fenton process was used with a dual function, namely oxidation and coagulation. The Fenton process is more expensive compared to the use of coagulant and flocculent agents, but these costs could be compensated by lower consumption of disinfection agents and by the lower costs of sludge handling and disposal.

2.4 Research on Innovative Wastewater Treatment Technologies in Morocco

Morocco is predicted to have a water deficit by 2020. The Souss-Massa region in Southern Morocco, for instance, is already under significant water stress.

The main industries in Morocco are food, tobacco, chemicals, mechanical, metal, electronics, construction materials, leather, and textiles. Industrial activity is concentrated in the north west of the country. Forty-nine percentage of industries are located in Casablanca. The majority of domestic and industrial wastewater of the urban and rural centers is discharged into the natural environment, without preliminary treatment. Rivers receive directly approximately 30% of total water pollution and 27% is absorbed by soil and groundwater.

Industrial effluents convey heavy organic and toxic pollution. 98% is poured into the sea (944.7 million of m^3) and the remainder into the water network or directly onto the ground.

The basic water law in Morocco is no. 10–95, which introduces the legislative, economic and organizational instruments necessary for the institution of a decentralized and participative water resource management and use program. One of the most important components of Law 10–95 is the creation of a water pollution tax based on the “user-pays” – “polluter-pays” principle, and quality protection [5].

The Moroccan Department of the Environment has also developed an incentive financial instrument to avoid industrial pollution under its FODEP program. The purposes of this program are to (1) ensure respect for the environment, (2) save natural resources, and (3) reduce water and air pollution and solid waste. This program, financed by the German Government, has a total budget of 240 million Dirhams (MDH) (about 22 million Euros). Pollution targeted is from small and medium-sized industry. This program provides financial support to downstream production wastewater, solid waste and air pollution treatment projects and integrated production projects aimed at reducing water pollution, solid waste or air pollution from the start, as well as saving resources (water, energy, etc.) by using non-polluting technologies.

This funding covers (1) the project technical study, (2) equipment necessary to avoid pollution, (3) construction tasks, and (4) safety equipment for workers. The project may be funded up to a maximum of 15 MDH for individual projects, and 30 MDH for collective projects. Up to time of writing, this program had funded 95 projects for a total amount of 44 million Euros of which 57 million are related to wastewater treatment. An example is the 155-thousand-Euros wastewater treatment station installed in a poultry slaughterhouse in Settat.

Being aware of the important threat that such diverse industrial wastewater means to Morocco’s natural water resources, several innovative studies related to the development of new treatment technologies have been performed by Moroccan researchers, sometimes in collaboration with foreign institutions. Many of these studies deal with treatment of textile industry effluents mostly by photocatalytic processes or electrocoagulation. For instance, evaluation of the efficiency of photocatalytic treatment of the model textile industry water pollutant Acid Red 88 dye, using Silica gel-supported titanium dioxide photocatalysts made by sintering TiO_2/SiO_2 mixtures with varied TiO_2 contents, calcination temperatures and times [27]. Furthermore, the photocatalytic degradation of the textile dye Basic Red 18 was evaluated for two different types of TiO_2, Degussa P25 (80% anatase) and Framitalia (100% anatase) [28]. Results were compared with the efficiency of decolorization using an H_2O_2/UV system. Finally, a marine mussel test was used to evaluate the efficiency of photocatalytic oxidation with TiO_2 for eliminating ecotoxicity. Moroccan researchers have also studied the feasibility of electrocoagulation for treating textile wastewater to determine the optimal operating conditions and find out which iron hydroxide, formed during electrolysis, is responsible for the electrocoagulation process [29]. The removal of coloring compounds from a textile effluent was evaluated by preparing the inorganic coagulants from electrolysis of NaOH, NaCl, and NaOH+NaCl solutions, using sacrificial aluminum electrodes operated at an electrical potential of 12 V [30].

Other researchers have focused, not on the development of a specific industrial wastewater treatment technology, but on assessment of poor water quality based on physicochemical and ecotoxicological analyses [31]. The studied area, located in the north of Morocco, included the River Sebou and its tributary the Fez River. The Mehrez Stream, which discharges huge amounts of untreated municipal and industrial wastewater into the Fez River, is also included. The sample period was from May 10 to 25, 2002. The major quality problems are low dissolved oxygen, high turbidity, organic matter and ammonia content, severe chromium and copper pollution and high acute and chronic toxicity. This results in the loss of the aquatic life which still flourishes in the Fez River upstream from the Fez Medina. Well water in the region of Fez has moderately poor quality with nitrate and metal enrichments. Use of water from rivers or from untreated wells for drinking or for agriculture may place the health of the population at risk.

2.5 Research on Innovative Wastewater Treatment Technologies in Palestine

Water use in Palestine is mainly agricultural, domestic, and industrial. Agriculture, with around 70%, is by far the largest consumer of water in Palestine, followed by domestic (27%) and industrial consumption (3%).

Some agricultural practices have contributed to deteriorating water quality. For example, excessive fertilizer in Jericho has led to nitrate leakage, which has been detected in elevated concentrations in ground water in some places. Furthermore, the uncontrolled application of pesticides is expected to contaminate springs and groundwater.

In the industrial sector, there are presently over 14,000 industries and factories on the West Bank and Gaza Strip, 70% of which are on the West Bank alone [32]. Most of them are located in Hebron, Nablus and Ramallah. Some types of industries causing damage to the Palestinian environment are leather tanning, textile dyeing, and production of food and beverages, olive oil, chemical and plastic (including pharmaceuticals, detergents, paints, adhesives, etc.) and metal processing, including electroplating, metal finishing and casting, which produce the most hazardous waste. Among these, food and beverage is one of the largest industrial sectors in Palestine [33].

Taking into account the highly detrimental effect of discharging industrial wastewater into domestic treatment plants without specific pre-treatment, little research has been done to characterize or minimize pollution dumped by industry. In this sense, some Palestinian authors consider anaerobic bioactive technology, specifically upflow anaerobic sludge blanket (UASB) systems, a good option for wastewater treatment in several areas of Palestine [34]. Composite sewage samples were collected from three locations in the Ramallah/AlBireh district and their chemical and physical parameters were analyzed. The results revealed that sewage in Palestine is characterized by its high concentration and solids content. Accordingly, the application of a one-stage UASB reactor is only possible if designed for a long water retention time due to low solid hydrolysis in the winter. However, reform in household sanitation habits should reduce the solids content, which would influence the selection of the proper treatment technology. In addition, factories should apply pre-treatment before discharging their wastewater into the municipal sewage system. This highlights the urgent need for issuing an environmental act and enforcing the implementation of environmental regulations.

3 Industrial Wastewater Treatment Processes Presently Applied in Mediterranean Basin Countries

The impact of water pollution from industry is critically affecting mainly Southern Mediterranean countries that have had continual industrial growth during the last decades (Tunisia, Egypt, Turkey, etc.), and look less ready to confront this question. All generally complain of the scarcity of remedial measures and WWTPs. The consequences are huge, considering that industrial estates tend to concentrate near the coasts or along rivers, overlapping with the problems of increasing urbanization. The question is essentially a problem of cost, because improved and cleaner technologies ensuring sustainable wastewater quality are expensive.

On the other hand the selection of the best available technology is not easy. It requires comparative technical assessment of the different treatment processes which have been recently and successfully applied for long periods of time at full scale. However, this alone is not sufficient; the selection should consider well-established criteria comprising average or typical efficiency and performance, reliability, institutional manageability, financial sustainability, application to reuse, and regulations. Furthermore, other parameters, such as wastewater characteristics, and the purpose of treatment as a qualification of desired effluent quality, which is mainly related to the expected use of the receiving water bodies, have to be carefully considered.

In this section, a review of industrial wastewater treatment processes presently applied in the Mediterranean Basin countries is presented with some examples.

In Turkey after 1980, for instance, serious work has been done on potable water, sewage, water treatment plants, and solid waste treatment and disposal. As a result of these efforts, wastewater management was improved: sewage services were provided to 13,400,000 inhabitants in metropolitan areas. In 1994, sewage served 52% of the total population, whereas in 2006 it had increased to 72% of total population. Wastewater treatment services were available to about 3.6 million people thanks to the cooperation of the Bank of Provinces. Many WWTPs were completed in big cities like Istanbul, Ankara and Izmir, and others are currently under construction. In rural areas, 2,540 villages now have simple sewage treatment services based on anaerobic sewage degradation in trenches.

In this country, three main types of treatment plant are generally preferred: for small communities (less than 20,000 inhabitants) ponds are the preferred choice, for middle-sized WWTPs trickling filters are preferred, and for large scale WWTPs either classical activated sludge or extended aerated activated sludge plants are preferred.

Sewage sludge from WWTPs is currently either used in agriculture or dumped in landfills. If the sludge is produced from industrial WWTP and contains poisonous materials, it is treated as hazardous waste material. The permission of the Environmental Ministry is necessary for the application of WWTP sludge to agriculture. The WWTP operators make the necessary analyses of the sludge and the soil and apply for approval to the Ministry [4].

Environmental consulting services and environmental equipment manufacturers are located in Istanbul, Ankara and some in the Aegean and Mediterranean area, in Bursa, Izmir, and Antalya. Some chambers of industry have already set up a waste exchange system in which one company's waste is made use of by another. The chambers industry of Izmir and Istanbul are working on this kind of projects.

In Tunisia, a complex, diversified water infrastructure allows the country to mobilize and exploit available water resources by adopting an integrated strategy based on scientific and technical studies. At the same time, Tunisia has put in place systems and legislation to assure access to drinking water for the majority of the urban and rural population, and to supply irrigation, as well as industry and tourism. On the other hand, total water demand, due to increased population and living standards, is forecast to reach its limit by the year 2030. Aware of this problem, Tunisia is engaged in formulating a strategy to more fully develop its water resources and to meet the demands of the various socio-economic sectors. The strategy focuses on demand management and integrated planning systems. The cost of developing additional water resources continues to rise.

At the end of 2007, there were 98 WWTPs in Tunisia, including those located in rural areas. The huge number of WWTPs developed by the ONAS (Office National de L'Assainissement – National Sanitation Utility) used recent technologies provided by automatic equipment and directed by specialized technicians. ONAS, a public, industrial and commercial institution under the Ministry of the Environment and Sustainable Development, is the Tunisian water quality protection authority.

On the other hand, taking into account the heavy industry that grew up in Egypt along the Nile Delta and in the Cairo and Alexandria metropolitan areas at the beginning of the fifties, wastewater in this area used to return about 85% of the water consumed by industry. This disposal into the Nile has almost stopped.

In Shoubra El Khaima (north of Cairo), untreated industrial wastewater is discharged daily into agricultural drains. The metropolitan area of Alexandria accommodates a multitude of industries in the vicinity of surface water, for example, in Amiria at Lake Marriott, near the Mahmoudia Canal, etc. In response to these environmentally unfriendly actions, the Egyptian government in collaboration with international organizations has introduced programs for adopting cleaner production and industrial wastewater treatment which have been active in the past decade [5].

In this sense, researchers at the Suez Canal University have also had extensive experience in the application and construction of wetlands for the treatment of domestic as well as industrial wastewater. Field experiments have concentrated on Abou Attwa Research Station (domestic wastewater) and The 10th of Ramadan Constructed Beds (industrial wastewater). This research generated a huge amount of information about installation, operation, and maintenance of Horizontal (Gravel Bed Hydroponics) as well as Vertical (Sand Filters) systems. This accumulated information was pooled in the construction of the First Sewage Treatment Plant in Egypt using artificial wetlands (Horizontal Flow of Gravel Bed Hydroponics) in El-Taqadoum Village, Sinai (1993).

A Gravel-Bed Hydroponic (GBH) system was also built and operated at the outlet of a large pond system at The 10th of Ramadan site for industrial wastewaters treatment. In The 10th of Ramadan City, 470 factories annually produce 3,000,000 m^3 of waste effluent, for which primary treatment is performed by oxidation ponds. Modular systems, incorporating vertical and horizontal flows and lagoons, will allow flow management to be adjusted according to the complexity of the industrial wastewater.

Morocco, with 800,000 tons per year, is another Mediterranean country producing a large amount of industrial wastewater. Only 20% of this industrial waste is recycled, and the remainder is stored uncontrolled in waste dumps or near production facilities [5]. Norms and standards must therefore be established, not only to control industrial pollution, but also for the reuse of treated wastewater adapted to local conditions. In practical terms, a pilot station was constructed in 1987 and 1989, and was brought into service in July 1989 (750 m^3/day treatment capacity). The treated wastewater quality meets WHO Category A recommendations for irrigation of products for raw consumption. The infiltration percolation treatment is efficient.

But, one of the most polluted effluents now comes from the tanning industry, which discharges organic and toxic pollutants (like trivalent chromium), as well as considerable solid waste. As a solution for small tanneries, for example, in Dokkarat, where 14 m^3/day are discharged with an average chromium concentration of 6,230 mg/L, a centralized chromium recovery facility was installed to collectively treat the effluents from all the units in the area. The recovery system consists of a sewer network (three branches with a total length of 3 km) where chromium-containing effluents flow by gravity to a concrete lift station. From there, the wastewater enters one of the four 50-m^3 receiver tanks, where grease and shredded leather fiber are separated, and floating grease is skimmed off. The used chromium solution is then pumped to one of the two reactor tanks where it is precipitated using caustic soda. A polymer is added to enhance precipitation, and the precipitate is transferred to the filter press where it is de-watered. Sulfuric acid is then added to the sludge to dissolve the precipitate and produce tanning liquor. The chromium recovered from the liquid is accumulated in a storage tank. Carboy is used to collect the recovered chromium on an as-needed basis for the tanners.

A final example are the Palestinian territories, where several projects have been started to rehabilitate old WWTPs and build new plants, pumping stations, groundwater wells, and sewage and drinking water networks. To date, only one project in Al-Bireh city has been implemented, while the others remain on hold (Table 3 [33]).

4 Research and Development of Innovative Technologies for Water Disinfection

Microbial pollution may have different human and non-human origins in different regions. If urban fecal wastewater is not treated before being discharged into a river, it can cause pollution further downstream. Cattle-raising close to rivers can cause microbial pollution of river water which is later used for irrigation, washing and sometimes even drinking. In addition to the well-known task of drinking water disinfection, the second most critical issue is the disinfection of water for agriculture. According to the United Nations Food and Agriculture Organization (FAO), agriculture consumes 70% of fresh water used worldwide. In developing countries, it is over 95% of the available fresh water [35].

Drinking water disinfection is defined by the destruction of microorganisms causing diseases, like cholera and typhoid fever. The mechanism involved is most commonly explained as the destruction of the organism's protein structure and inhibition of enzymatic activities [36]. This definition leads to the generalized use of high-level disinfectants such as ozone and chlorine compounds and resulting resistance of microorganisms, including prions, followed by coccidian (*Cryptosporidium*) and bacterial spores (*Bacillus*), mycobacteria (*Mycobacterium tuberculosis*), viruses (poliovirus), fungi (*Aspergillus*), leading finally to Gram-negative (*Pseudomonas*) and Gram-positive bacteria (*Enterococcus*). This resistance is mainly due to the cell wall permeability to the specific disinfectant, although size and complexity of the microorganism also influence its resistance.

Conventional drinking water pre-treatment techniques, such as coagulation, flocculation, and sedimentation remove a maximum of 90% of bacteria, 70% of viruses and 90% of protozoa. Filtration for drinking-water treatment only with proper design and adequate operation, can act as a consistent and effective barrier for microbial pathogens leading to approx. 99% bacteria removal. Depending on the water source, the remaining bacteria might still be able to cause disease, which makes filtration a good pretreatment, but not a completely safe disinfection technique. For highly resistant microorganisms, filtration in combination with chlorine is recommended [37].

Table 3 Wastewater treatment plants in the West Bank (status and general information)

Name of the treatment plant	Status of the treatment plant	No. of population served by the treatment plant[a] 1,000 (year)	Capacity of the treatment plant (mcm/year)	Funding agency	Estimated cost for construction (million US $)	Technology
Nablus East	Planning phase	240 (2021)	9.2	Germany KfW	25	Extended aeration
Nablus West	Approved	225	9.0		25	
Salfeet	Detailed study	24 (2025)	2.3	Germany KfW	13	Extended aeration
Jenin[a]	Rehabilitation is needed	13.5 (1997)	0.5	Israel		Waste stabilization ponds
Al-Bireh	Constructed	40 (2000)	1.1	Germany KfW	7	Oxidation ditch
Tulkarm[b]	No study yet	223 (2030)	7.5	Germany KfW	50	Extended aeration process
Abu-Dees	Feasibility study	26 (2020)	1	Norway		Oxidation ditch
Tafuh	Feasibility study	16	0.5	UNDP		Anaerobic rock filter
Halhul	Preliminary design	42 (2020)	1.0	Not funded	5.5	Aerated pond system
Birzeit area	Preliminary study	28 (1994)	1.2	Not funded	4.5	Imhoff tank and trickling filter
Hebron	Planning stage	695 (2020)	25.0	USA	45	Activated sludge
Jericho	Preliminary study	26 (2000)	1.2	Not funded		
Biddya	Preliminary study	24 (2000)	1.1	Not funded	10.0	
Ramallah[c]	Feasibility study	40 (north)	1.5	Not funded	7.0	Extended aeration
		40 (south)	1.5		7.0	
Al-Ram	Preliminary study	86.5 (2000)	3.3	Germany KfW	11.0	Aerobic sludge stabilization + activated sludge
Total		1,789	66.3		210	

[a]Old and/or inoperative sewage treatment plants
[b]Rehabilitation of the sewage treatment plant currently underway
[c]Rehabilitation of the old sewage treatment plant currently underway as a partial solution

The most commonly used drinking water disinfection techniques; chlorination (chlorine and derivates), UV-C, and ozonation are the safest for most infectious agents. UV-C disinfection and ozonation have associated installation, electricity and maintenance costs. But both techniques are very effective in killing bacteria and reasonably effective in inactivating viruses (depending on type) and many protozoa, including *Giardia* and *Cryptosporidium*. 99% of bacteria can be removed with 0.02 mg of ozone per min and liter at 5°C and pH 6 – 7. For the disinfection of *Cryptosporidium,* the highest ozone concentration is needed: 40 mg per min and liter at 1°C [38]. Despite its highly efficient inactivation of all microorganisms present, ozonation can also produce disinfection by-products (DBPs), depending on source-water quality.

Chlorine is a very effective disinfectant for most microorganisms. 99% of bacteria and viruses can be successfully disinfected with chlorine. Nevertheless parasites like *Cryptosporidium* cannot be safely inactivated with chlorine at all [37]. The protozoa *Cryptosporidium, Giardia* and *Acanthamoeba,* which are very highly resistant to chlorine, present a high risk of infection and are extremely persistent in water supply systems. Such significant resistance makes it clear that an alternative to chlorine as a general disinfectant must be found. These protozoa, as well as *Campylobacter jejuni, Campylobacter coli, Yersinia enterocolitica, Pseudomonas aeruginosa*, have been successfully inactivated by solar or solar photocatalytic disinfection. The other main disadvantage of chlorine is the appearance of by-products, organohalides, especially trihalomethanes (THMs), in chlorinated drinking water. These undesirable compounds have led to severe criticism of its use in drinking water and even in irrigation water.

4.1 Solar Disinfection

Solar UV radiation reaching the Earth's surface contains UV-B and UV-A light. UV-B radiation is believed to be the component of sunlight mainly responsible for the majority of solar injury to humans, since this spectral region overlaps with the tail of DNA absorption. The UV-A region of sunlight is also potentially carcinogenic and is partly responsible for photo-aging [39]. Today it is accepted that the damage caused by UV-A and UV-B light is mainly due to its absorption by cell components called intracellular chromophores. The irradiation of intracellular chromophores with UV-A light is only toxic to cells in the presence of oxygen. Chromophore damage by light absorption is therefore contributed to by the generation of reactive oxygen species (ROS). The resulting oxidative stress damages the cells and cell components [40]. ROS can lead to lipid peroxidation [41], pyrimidine dimer formation [42] and even DNA lesions [43]. When ROS interact with DNA, single strand breaks (SSBs) occur as well as nucleic base modifications which may be lethal and mutagenic. Furthermore, oxidation of proteins and membrane damage is also induced.

Many publications have reported on the exclusive use of solar radiation for treatment of water polluted by organic compounds and microorganisms. It has been demonstrated to eliminate a large amount of organic and pathogenic organisms avoiding toxic by-product generation typical of the conventional technologies. The first publication on the application of sunlight to drinking water disinfection was by Acra et al. [44], who demonstrated that sunlight can disinfect oral rehydration solutions. In developing countries where it may be difficult to obtain drinking water free of pathogenic organisms, the need for an effective but practical water disinfection method is still of vital importance [44].

Solar disinfection (SODIS) has been shown to be a practical, effective household treatment method with low operating costs. Through a synergistic effect of mild heat and UVA light, microbial pathogens in drinking water contained in poly (ethylene) terephthalate (PET) bottles are inactivated within 6 h after exposure to sunlight [44]. Acra et al. reported that enteric bacteria were inactivated after exposure to 6 h of sunlight. Subsequently, other organisms have been tested, including *Salmonella typhimurium, Shigella dysenteria, Escherichia coli, Vibrio cholera* and *Pseudomonas aeuriginosa* [45, 46], protozoan oocysts of *Cryptosporidium parvum* and cysts of *Giardia muris* [47], the yeast *Candida albicans*; the fungus, *Fusarium solani* [48], several phytopathogenic fungi of *Fusarium* genera [49] and *Polio* virus [50].

Although the results of SODIS are very promising, it is only used for disinfection in remote low-income areas without access to clean drinking water. The suitability of the SODIS technique for countries with a high incidence of waterborne disease is further illustrated by the fact that these countries lie in the latitude lines of 30°N and 30°S and hence receive sufficient sunlight to apply SODIS. The effectiveness of the process depends on the original water quality, temperature, turbidity, and resistance of the specific microorganisms, irradiance and dissolved oxygen. Over 45°C, there is a synergy between thermal heating and solar UV inactivation which leads to improved disinfection [51]. Even extremely turbid water (200 NTU) can be disinfected under Kenyan sunlight after storing for 7 h at temperatures of 55°C or higher [52].

SODIS as a drinking water treatment has important advantages to alternative treatments: (1) availability in low-income, sun-rich areas; (2) acceptance due to natural odor and taste of the water (often not the case for chlorine); (3) sustainability as no chemicals are consumed; and (4) no need of post treatment after disinfection.

Nevertheless, some scientific and technical issues are still under study. The goal of recent research on SODIS is to overcome limitations of this technique like: (1) the length of time required for inactivation, for example, on cloudy days, two consecutive days of exposure are recommended; (2) the volume of clean water generated by SODIS is very small, a maximum of 3 L per bottle; (3) several pathogens (especially resistant spores and viruses) remain untested; (4) when turbidity of water is very high (>100 NTU) exposure times become longer and disinfection cannot always be ensured for all waterborne pathogens.

4.2 Water Disinfection with TiO_2 Photocatalysis

Since 1985, more than 160 peer-reviewed articles have been published on TiO_2-assisted water disinfection alone, applied to a wide range of microorganisms. Ireland et al. [53] reported on disinfection of pure cultures of *E. coli* with anatase crystalline TiO_2 in a flow-through water reactor. Their work focused on drinking water disinfection of natural water samples was one of those with the most impact and citations on TiO_2 disinfection [53]. Later, other contributions with better disinfection yields have been published using TiO_2 and different photon sources.

TiO_2 disinfection research has gone from basic laboratory studies to the first trials with real disinfection applications. In 2000, Herrera Melian et al. reported on TiO_2-assisted disinfection of urban waste water [54], while Rincón and Pulgarin did not find any modification in the inactivation rate of *E. coli* in distilled water due to changes in initial pH between 4.0 and 9.0 in the absence or presence of TiO_2-P25 under simulated sunlight illumination [55]. Microorganisms very resistant to UV-A irradiation like *Enterobacter cloacae* and other Gram-negative strains of bacilli with differing photosensitivity, such as *E. coli*, *P. aeruginosa* and *S. typhimurium* have been successfully inactivated by TiO_2 photocatalysis [56].

Recent TiO_2 disinfection research focuses more on disinfection applied to more resistant microorganisms. Seven et al. inactivated *E. coli*, *P. aeruginosa*, *Staphylococcus aureus*, *Saccharomyces cerevisiae* and *C. albicans* in the presence of TiO_2, ZnO and Sahara desert sand under lamp irradiation [57]. Lonnen et al. confirm inactivation of *C. albicans* by TiO_2 photocatalysis and report a 5.5-log decrease in *F. solani* after 4 h of simulated sunlight. This group was the first to publish such high inactivation rates with a fungal test organism, and especially, with supported TiO_2 [48].

The main concern of TiO_2 slurry disinfection is the need for post-treatment TiO_2 recovery. Contrary to small concentrations of chlorine, TiO_2 powder cannot be left in drinking water due to insufficiently assessed health risks. Therefore, much research has been done on efficient catalyst supports that would keep the TiO_2 out of the treated water. Unfortunately, in photocatalytic disinfection, almost all immobilized TiO_2 either has had very limited yields or involved technical effort leading to high cost. It was even reported that immobilization of TiO_2 produces lower disinfection activity compared to slurry systems [58, 59].

The choice of the source of light and reactor configuration can make the final disinfection results totally different. The spectral distribution of the source of photons strongly affects the inactivation result. For example, if a lamp partly irradiates within the UV-C range, the bactericidal effect is very fast, even in absence of a catalyst. Apart from the spectral distribution, the irradiance (e.g., the radiant energy per unit of time and cross-section) are very important parameters. The irradiation pathway in the photoreactor also has a strong influence on disinfection. When light exposure is continuous (without interruption) the bactericide effect is faster and more efficient than when light is intermittent [59, 60]. Some contributions suggest that this effect may be due to a bacterial repair mechanism which responds when radiation is interrupted and bacteria are thus able to re-activate after treatment [60, 61].

The main concern in using Fenton-like processes for water disinfection and water treatment in general is the competition for •OH radicals between the pollutant and ligands, which maintain the iron in solution. Once the organic ligands are oxidized, the iron is no longer held in solution at neutral or near neutral pH. The need of Fenton processes for low pH for reactions has also been strongly criticized. At pH around 3, most microorganisms are no longer viable without the need of further treatment. The only recent work about photo-Fenton treatment for disinfection was published by Rincón and Pulgarin for *E. coli* [62]. The authors used real water from Lake Lemans in Switzerland, concentrations of 10 mg/L of iron from iron salts and 10 mg/L H_2O_2 at neutral pH. Their promising disinfection results have opened the way to a new water disinfection method.

To date, lethal synergy has not been discussed in the context of the Fenton reaction after iron up-regulation following UV-A-induced ROS attacks up to the publication by [63]. This article reports results of inactivation of fungal cells in distilled and well water using H_2O_2 at very low concentrations and sunlight. The synergic effect of hydrogen peroxide and solar photons is attributed to the generation of •OH radicals from H_2O_2 after the Fenton reaction. As radical production in combination with sunlight and iron is closely connected to skin cancer, and therefore, the medical field, the topic is of great interest and many studies have been published in the last few years.

4.3 Research on Water Disinfection in Mediterranean Basin Countries

Research in disinfection technologies recently performed in the South Mediterranean and Middle East Regions is worth mentioning. Bohrerova et al. [64] proposed a new Pulsed UV system (PUV), a novel non-mercury lamp alternative UV irradiation to currently used continuous-wave UV irradiation systems for water disinfection [64]. The authors show the inactivation of *E. coli* and phage T4 and T7 as pathogen surrogates. Inactivation was significantly faster using PUV irradiation. Enhanced PUV inactivation was significantly more efficient at wavelengths over 295 nm.

Komesli et al. [65] studied a vacuum membrane bioreactor (MBR) [65] with a flat membrane with 0.038-μm pores and a 540 m^2 surface, which was operated intermittently for over a year on the METU campus at Ankara to treat domestic effluents from dormitories and academic village. Effluent turbidity, was always below 1 NTU, equal to or below that of tap water, and around 6–7 log coliform removal with effluent counts close to zero/100 mL were achieved.

Mamane et al. [66] evaluated the potential of an advanced oxidation process (AOP) for microbiocidal and virucidal inactivation. The viruses chosen for this study were bacteriophage MS2, T4, and T7. *Bacillus subtilis* spores and *E. coli* were also studied. H_2O_2 in the presence of filtered ultraviolet (UV) irradiation (UV/H_2O_2) at wavelengths above 295 nm minimized the direct UV photolysis disinfection mechanism, while disinfection by H_2O_2 was also negligible. Virus T4 and *E. coli* in phosphate buffered saline (PBS) were sensitive to filtered UV irradiation >295 nm (without H_2O_2), while MS2 was very resistant. Addition of H_2O_2 at 25 mg/L in the presence of filtered UV irradiation over a 15-min reaction time did not result in any additional disinfection of virus T4, while there was an additional 1-log inactivation for T7 and 2.5 logs for MS2. Only a slight additional effect was observed on *E. coli* when H_2O_2 was added. *B. subtilis* spores did not show any inactivation at any of the conditions used in this study [66].

Ksibi [67] worked on oxidation with hydrogen peroxide. Bacteria inactivation efficiencies in secondary effluents by H_2O_2 oxidation were investigated. The number of total coliforms exponentially decreased with increasing dose and fell to low levels at a dose of 2.5 ml/L [67].

Nasser et al. [68] evaluated the comparative disinfection efficiency of UV irradiation on viruses, bacteria, and spores. The microbial quality of effluents treated by coagulation, high-rate filtration (HRF), and either UV irradiation or chlorination was analyzed. A UV dose of 80 mWs/cm^2 was needed to achieve a 3-log inactivation of either rotavirus SA-11 or coliphage MS2, whereas over 5-log inactivation of *E. coli* was reached with a dose of only 20 mWs/cm^2. *B. subtilis* inactivation was found to be linear up to a dose of 40 mWs/cm^2 and then slowed down ("tailing" behavior) up to a UV dose of 120 mWs/cm^2 [68].

Jemli et al. [69] carried out a small-scale study of the destruction of fecal coliforms in wastewater using three photosensitizers (Rose Bengal, Methylene Blue, cationic porphyrin). By increasing the duration of irradiation they improved the log reduction in bacteria and compensated for lower concentrations or less efficient sensitizers [69].

Alouini and Jemli [70] worked on the destruction of helminth eggs by photosensitized porphyrin, as Tunisian untreated wastewater contains an average of 30 human helminth eggs per liter. After treatment, the concentration decreases to one egg per liter, or less in some cases. The percentage removal quoted for wastewater processes provides no real indication of the destruction of the organisms, but merely of their transfer to another medium. Microorganism photosensitization is potentially useful for sterilization and for the treatment of certain bacterial diseases. Gram-positive bacteria can be photo-inactivated by a range of photosensitizers, but Gram-negative bacteria are not usually susceptible to photosensitized destruction [70].

Makni [71] studied disinfection of secondary effluents by infiltration percolation. In Tunisia, most wastewater plants are only for secondary treatment and, according to health regulations, the effluents must be disinfected. However, secondary effluents commonly require filtration prior to disinfection [71]. Effectiveness of conventional disinfection processes, such as chlorination and UV radiation, are dependent upon the oxidation level and the levels of suspended solids of the treated water. Ozonation is relatively expensive and energy consuming. Analysis of the advantages and disadvantages of conventional techniques, their reliability, investment, and operating costs can lead to the use of less sophisticated alternative techniques for certain facilities. Among alternative techniques, soil aquifer treatment and infiltration percolation through sand beds have been studied in Arizona, Israel, France, Spain, and Morocco. Infiltration percolation plants have been intermittently fed with secondary or high quality primary effluents which percolated through 1.5–2 m of unsaturated coarse sand and were recovered by under-drains. In such infiltration percolation facilities, microorganisms were eliminated through numerous physical, physicochemical and biological interrelated processes (mechanical filtration, adsorption and microbial degradation respectively). Efficiency of *fecal coliform* removal was dependent upon the water detention times in the filtering medium and on the oxidation of the filtered water. Effluents of Sfax town aerated ponds were infiltrated through 1.5-m deep sand columns to determine the performance of infiltration percolation for polishing secondary effluents. Elimination of bacteria (total and *coliforms, fecal streptococci*) and their relationship with the hydraulic load and the temperature were investigated.

On the other hand, the disinfection technology most employed in Europe is ozonation. The bactericidal effects of ozone have been documented on a wide variety of organisms, including Gram positive and Gram negative bacteria as well as spores and vegetative cells [72]. Iske et al. [73] compared disinfection by ozonation and UV-irradiation of biologically treated wastewater from two different municipal treatment plants, one treating mainly domestic wastewater and the other containing some industrial effluents [73]. Sanitary, chemical and eco-toxic effects of the disinfection step were examined. Guideline and legal requirements for fecal and total coliform bacteria were met by both ozonation and UV-irradiation. UV-irradiation induces no changes concerning chemical wastewater quality and toxic effects. However, ozonation can lead to alterations in chemistry and toxicity depending on the wastewater composition. Chand et al. [74] used a novel approach of ozone and a liquid whistle reactor (LWR), which generates hydrodynamic cavitation for water disinfection. A simulated effluent having an *E. coli* concentration of approximately 10^8 to 10^9 CFU mL^{-1} was entered in the LWR to examine the effect of hydrodynamic cavitation alone and in combination with ozone. Operating inlet pressure and ozone dose as well as ozonation time for operation alone and together have been varied to maximize disinfection and determine the optimum treatment strategy. Nearly 75% disinfection can be achieved in about 3 h of treatment using an optimized combination of hydrodynamic cavitation and ozonation. This combination has been found to be a cost-effective technique for achieving maximum disinfection compared to the individual operation of hydrodynamic cavitation [74].

5 Conclusions

From this general overview on actual and innovative industrial wastewater treatment technologies in Mediterranean Basin Countries, some negative conclusions must be considered:

- Legislation is poorly or unsatisfactorily implemented because of various factors, most commonly lack of enforcement, insufficient resources (human, structural, financial), and inefficient or slow application procedures.
- In some countries, there are many agencies or administrations whose jurisdiction overlaps on the same issues, sometimes resulting in poor or no coordination and conflicting decisions. This hampers proper knowledge of management matters and strongly affects application of the law and measures, for example for pollution.

Scarcity of water resources and the need to protect the environment and natural resources are the main factors leading Mediterranean Countries to introduce treated wastewater as an additional water resource in their national water resource management plans. Water quality and a strategy and policy to promote wastewater reuse are necessary. The treatment system to be used for this would depend on how the wastewater is to be reused. Cost/benefit analysis should include social, economic, and environmental aspects. Finally, there is also a need for emphasis on community and end user information and education programs with wastewater reuse program demonstration plants to show the advantages and disadvantages.

From a practical point of view, it is very important to be aware of the real situation in each Mediterranean Country before suggesting innovative treatment technologies still in experimentation, and the first steps of application to wastewater treatment and reuse systems in developed countries. Furthermore, conventional technologies and available WWTPs in some of the Mediterranean Countries are not working properly or even out of use due to high maintenance costs and highly qualified people required for their daily operation and control. New emerging technologies could therefore be proposed for heavily polluted effluents:

- Tertiary treatments: Advanced Oxidation Technologies (catalytic wet air oxidation, ozonation, high-temperature Fenton, photo-Fenton – preferably with solar energy to reduce operating costs – electro-Fenton, etc.).
- Biological treatments: Advanced anaerobic treatment, MBRs, alternating anaerobic and anoxic treatments, etc.
- Chemical and biological integrated systems in order to reduce the treatment plant operational costs.
- Water reuse treatments: Reverse osmosis systems, ultrafiltration, and nanofiltration.

A general conclusion could be oriented around the expense of wastewater systems, which are generally capital-intensive and require highly paid specialized operators. This becomes especially important when new techniques are to be applied for high-quality reusable water. Therefore, study and selection of a wastewater treatment technology should include an analysis of cost effectiveness and be compared with all conceivable alternatives, taking into account that due to their climate, solar energy can be used in these countries to significantly reduce operating costs.

Apart from the above considerations, some issues remain to be addressed in future work, among them water and energy issues. For example, the numerous water–energy interactions, which are becoming more and more important in today's energy context, must also be understood to develop global sustainable water management.

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Innovative Wastewater Treatments and Reuse Technologies Adapted to Southern Mediterranean Countries

Redouane Choukr-Allah

Abstract Southern Mediterranean countries are characterized by severe water imbalance uneven rainfall and, at the same time, are unable to meet their food requirements using the available water resources. Treated and reused sewage water is becoming a common source for additional water. Some of these countries have included wastewater treatment and reuse in their water planning. This will narrow the gap between freshwater supply and demand in different water use sector. The urban areas of many Mediterranean countries are growing rapidly, and ecological sanitation systems must be implemented that are sustainable and have the ability to adapt and grow with the community's sanitation needs, taking in consideration the social, economic, environmental, and institutional of the local conditions. Choosing an appropriate innovative treatment technology for Southern Mediterranean countries will include lagoons/wetlands, sand filter, and soil aquifer treatment. Within this framework, the main objective of this chapter is to demonstrate the appropriate technologies of wastewater treatment adapted to the Southern Mediterranean region.

Keywords Reclamation, Recycling, Reuse, Treatment technologies, Wastewater, Water scarcity

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1 Introduction

In the Mediterranean countries, there is an urgent need to improve the efficiency of water use, to implement water demand management practices, and to augment the existing sources of water with more sustainable alternatives. Numerous solutions, modern and traditional, exist throughout the world for efficiency improvements and augmentation. Treated wastewater reuse has become increasingly important in water resource management for environmental, economic, and social reasons. As urban development increases in the Mediterranean basin, the quantity of waste generated also increases. These wastes pose a serious threat to public health when they are not appropriately disposed of. The use of domestic wastewater for irrigation is advantageous for many reasons including water conservation, ease of disposal, nutrient utilization, and avoidance of surface water pollution [1]. Nevertheless, it must be borne in mind that although the soil is an excellent adsorbent for most soluble pollutants, domestic wastewater must be treated before it can be used for crop irrigation to prevent the risk to both public and the environment.

The implementation of low cost treatment is recommended. Properly designed, adequately implemented wastewater reuse is an environmental protection measure that is superior to discharge treated wastewater to its end use of the reclaimed effluent need to meet the guidelines, taking into consideration the economic constrains. Usually the wastewater of domestic population does not contain heavy metal, which means that the main concern of treatment will focus on the removal of pathogens. Several technologies will be described in this chapter to be adapted on the socioeconomic conditions of the local population.

The lower the financial costs, the more attractive is the technology. However, even a low cost option may not be financially sustainable because this is determined by the true availability of funds provided by the polluter. In the case of domestic sanitation, the people must be willing and able to cover at least the operation and maintenance cost of the total expenses. The ultimate goal should be full cost recovery, although, initially, this may need special financing schemes, such as cross subsidization, revolving funds, and phased investment programs.

In this regard, adopting an adequate policy for the pricing of water is of fundamental importance in the sustainability of wastewater treatment systems. Subsidizing treatment system may be necessary at the early stages of system implementation, particularly when the associated costs are very large. This would avoid any discouragement to users arising from the permitted use of the treated wastewater.

Although the environmental enhancement provided by treated wastewater use, particularly in terms of preservation of water resources, improvement in the health status of poor populations in rural areas, the possibilities of providing a substitute for freshwater in water scarce areas, and the incentives provided for the construction of sewerage networks, are extremely relevant. They are also sufficiently important to make the cost benefit analysis purely subsidiary when taking a decision on the implementation of wastewater treatment systems, particularly in poor and rapidly growing rural villages.

The major bottlenecks facing most of the South Mediterranean countries are due to a lack of explicit national or government strategy (master plan) for water sanitation and the extended reuse of wastewater to efficiently address the local water scarcity/stress problems. The potential for treated wastewater reuse is still underexploited. However, some countries are more advanced than others. The overloading of certain treatment plants, and non performing treatment technologies and capacities, resulting in insufficient water quantities of appropriate quality for reuse; as well as inadequate pre-treatment of industrial wastewaters, which are often directly discharged into the general sewerage systems and mixed with domestic wastewaters, thereby either limiting the reuse potential or exceeding the treatment capacity of the wastewater treatment plants. The limited cost recovery via water fees/tariffs and/or governmental subsidies for operation and maintenance of treatment facilities has also a negative effect on the performance of WWTPs and limits the reuse potential.

2 Wastewater Treatment Adapted to Southern Mediterranean Countries

In Southern Mediterranean countries, the removal or inactivation of excreted pathogens is the principal objective of wastewater treatment, and treatment to levels proposed by Blumenthal et al. [2] should be adequate to protect public health. Conventional wastewater treatment options (primary and secondary treatments) are often better at removing environmental pollutants than removing pathogens, however, and many of these processes may also be difficult and costly to operate properly in developing country situations. Waste stabilization ponds (WSPs), when designed and operated properly, are highly effective at removing pathogens [3] and can be operated at low cost where inexpensive land is available. They are designed to use natural processes of biodegradation, disinfection by sunlight, and particle settling under gravity, to purify the water. They form a series of shallow ponds linked together to maximize retention time. However, WSPs should be designed, operated, and maintained in such a way as to prevent disease vectors from breeding in the ponds [4]. In order to achieve the quality of effluent to be used for different purposes, the train to follow is illustrated in Fig. 1

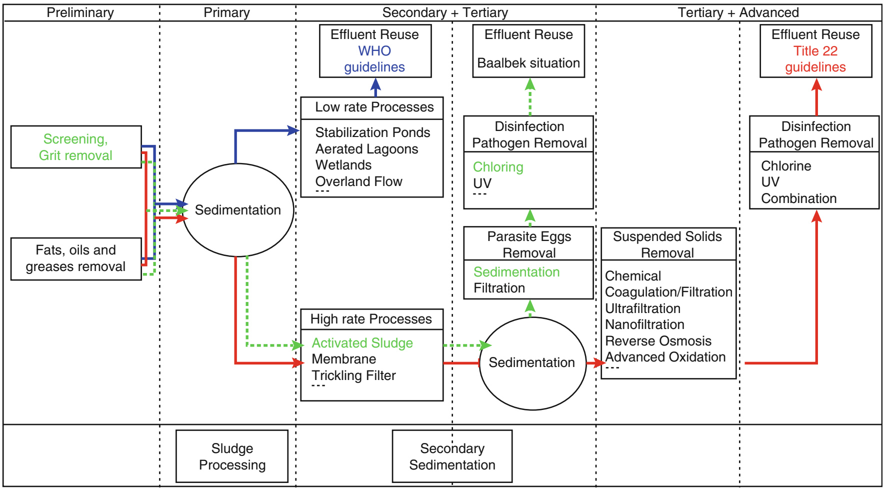

Fig. 1 Train to reach different effluent reuse guidelines

2.1 Stabilization Ponds

Anaerobic wastewater treatment differs from conventional aerobic treatment in that no aeration is applied. The absence of oxygen leads to controlled anaerobic conversions of organic pollutants to carbon dioxide and methane, the latter of which can be used as energy source. The main advantages of anaerobic treatment are the very high loading rates that can be applied (10–20 times as high as in conventional activated sludge treatment) and the very low operating costs. Anaerobic treatment often is very cost-effective in reducing discharge levies combined with the production of reusable energy in the form of biogas. Pay-back times of significant investments in anaerobic treatment technologies can be as low as 2 years. Anaerobic treatment of domestic wastewater can also be very interesting and cost-effective in countries where the priority in discharge control is in removal of organic pollutants.

WSPs are now regarded as the method of first choice for treatment of wastewater in many parts of the world. In Europe, for example, WSPs are widely used for small rural communities (up to populations of about 2,000, but large systems exist in Mediterranean France and also in Spain and Portugal) [5]. However, in warmer climates (the Middle East, Africa, Asia, and Latin America), ponds are commonly used for large populations (up to 1 million). In natural treatment systems such as WSP, the pathogens are progressively removed along the pond series with the highest removal efficiency taking place in the maturation ponds [6].

The disadvantages of the WSPs are that large land areas are required and that their construction may only be feasible when land values are low [7]. WSPs lose their comparative cost advantage over mechanized treatment systems when land prices are greater than US$15–20/m^2 [8].

2.2 Sheaffer Modular Reclamation System

The Sheaffer system is described as a *Modular Reclamation Reuse System* [9] producing no sludge, no odors, and enabling 100% recovery of nutrient rich water for irrigation. The system is composed of a deep aerated treatment cell, a storage cell, and three moving parts, described as a grinder pump, a compressor/blower, and an irrigation system [10]. Solid components are broken down into simple organic acids, methane, carbon dioxide, sulfide, ammonia, inorganic compounds, and water. The nitrogen, phosphorus, and potassium are dissolved and remain in solution for use in agricultural irrigation.

2.3 Constructed Wetlands

Wetlands constructed are known as "constructed wetlands" and are effective in the removal of BOD, TSS, and nitrogen [11, 12]. Some of the earliest studies using forested wetlands to treat domestic wastewater demonstrated that nutrients could be removed with a minimum application of expensive and fossil energy consuming technology [13]. Subsurface wetlands are lined ditches that have been filled with a gravel, sand, or soil substrate and planted with appropriate plant varieties. Treatment in subsurface systems generally occurs when the effluent makes contact with plant roots and the soil or rock bed [14]. One of the major advantages of reed bed treatment systems is the low maintenance requirements [14, 15].

Free-water surface (FWS) wetlands are typically shallow channels or basins where the water surface is open to the atmosphere and a suitable medium exists to support the growth of emergent or submerged aquatic plants [16]. Two floating aquatic macrophyte plants, water hyacinth (*Eichhornia crassipes*) and duckweed (*Lemnacea* sp., *Spirodella* sp.), have been most commonly used in wastewater treatment systems at this time. Compared to water hyacinth, duckweed-based wastewater treatment systems play a smaller role in BOD removal, but are efficient in the removal of nutrients and can play a significant role in TSS reductions [17].

2.4 Sand Filter System

Sand filtration is one of the oldest wastewater treatment technologies known. If properly designed, constructed, operated, and maintained, a sand filter produces a very high quality effluent. Sand filters are beds of granular material, or sand, drained from underneath so that pretreated wastewater can be treated, collected, and distributed to the land application system.

Types of sand filters include intermittent sand filter (ISF) and recirculating ISF, and the main advantages of the system are as follows:

- Sand filter treatment systems are extremely “Passive”. That means there’s minimal mechanical equipment to wear out and require replacement. This saves cost and associated hassles.
- You get an environmentally “green” process which produces valuable reusable water for lawn or garden requirements.
- Negligible electrical power consumption. The filter and effluent pumps operate for approximately 10 min/day. A solar option is also available.
- Natural disinfection. No chemicals to create negative environmental impacts. Furthermore, sand filter treatment systems has the added ability to deactivate and remove viruses and helminths from secondary effluent.
- Proven to generate an extremely consistent and high quality effluent. Can tolerate wide hydraulic or organic loading fluctuations.
- The sand filter sewerage treatment system is a scalable technology suitable for commercial, industrial, and institutional settings.

3 Criteria for Choosing Wastewater Treatment Technology

The urban and rural sectors in the Southern Mediterranean countries have suffered from much neglect as far as its sewage, wastewater treatment, and wastewater reuse are concerned. The problem has become more acute in recent years due to the sharp increase in the domestic water demand, due to the continued water shortage, and due to the strive to raise standard of living [18].

Falling behind in the wastewater management and reuse caused raw sewage to flow in the public roads, thus causing contamination of ground water, local wells, and drinking waters, creation of nuisances, and danger of public health with frequent outbreaks of water-borne diseases. Unauthorized irrigation was the main source of cholera outbreaks in Southern Mediterranean countries with many hospitalized people and many fatalities [19]. Such outbreaks also caused a severe reduction in the tourism to some countries and may have affected the tourist industry in these countries for several years.

Urban and rural area communities in Southern Mediterranean countries have several features in common that guide the design and operation of wastewater treatment plants, as follows:

1. Need for wastewater reuse for irrigation during the long dry summer months and the need for seasonal storage of wastewater from winter to summer.
2. Usually enough inexpensive land area around and adjacent to the urban community is available.
3. Sunlight is usually abundant in these regions, giving advantage to photosynthetic and other solar-energy-dependent processes.

4. Relatively concentrated wastewater due to limited per capita water consumption rate.
5. Relatively high pathogenicity of the wastewater due to endemicity of certain diseases and high proportions of carriers.
6. Shortage of capital investment.
7. Absence, shortage, or unreliability of electrical power.
8. Need for minimal, simple, and inexpensive operation and maintenance of facilities.

The motivation for investments in wastewater treatment plants can be increased using the treated effluent for agricultural irrigation. This will add an economical value force both for increasing capital investments and the expenses needed for proper operation and maintenance of the wastewater treatment facilities. Effluent quality aspects are also influenced by the decision to use the effluent for irrigation, since the demand for high removal efficiency of pollutants such as nitrogen and phosphorous does not exist, while the treatment technology should be directed for high hygienic demands. By using the effluent for controlled irrigation, much of the environmental risks caused by other effluent disposal alternatives (e.g., disposal to rivers, lakes, and sea) are prevented, so it is obvious that both the farmers and the environment can be benefited from effluent reuse in small communities.

The selection of technologies should be environmentally sustainable, appropriate to the local conditions, acceptable to the users, and affordable to those who have to pay for them. In developing countries, western technology can be a more expensive and less reliable way to control pollution from human domestic and industrial wastes. Simple solutions that are easily replicated, that allow further upgrading with subsequent development, and that can be operated and maintained by the local community are often considered the most appropriate and cost-effective. The choice of a technology will depend on the type of reuse. The selection of reuse option should be made on a rational basis. Reclaimed water is a valuable but a limited water resource; hence, investment costs should be proportional to the value of the resource.

Indeed, the selection of the best available technology is not an easy process: it requires comparative technical assessment of the different treatment processes which have been recently and successfully applied for prolonged periods of time, at full scale. However, this is not sufficient, and the selection should be carried out in view of well-established criteria comprising: average or typical efficiency and performance of the technology; reliability of the technology; institutional manageability, financial sustainability; application in reuse scheme and regulation determinants. Furthermore, for technology selection, other parameters have to be carefully considered: wastewater characteristics, the treatment objectives as translated into desired effluent quality which is mainly related to the expected use of the receiving water bodies.

Presently, there are a limited number of appropriate treatment processes for Southern Mediterranean countries which should be considered. These include stabilization ponds or lagoons, slow sand filters, land treatment systems, and constructed wetlands. All of these fit the operability criteria discussed above and, to varying degrees, are affordable to build and reliable in their treatment performance. In order to illustrate the viability of these systems, the following example is provided. In this example, a medium-size community collects its wastewater from the treatment site, and the effluent will be required to meet WHO standards for unrestricted agricultural irrigation.

Many researchers have found a high variability of stabilization ponds in their capability to consistently meet WHO microbiological criteria. Therefore, the designer may wish to supplement the ponds with a tertiary system to meet the criteria consistently. Appropriate stabilization pond upgrading methods to meet WHO reuse standards include FWS constructed wetlands, which can provide both the detention time of required maturation ponds of the same size and removal of algae from the pond effluent which can clog some irrigation systems; ISFs, which remove the parasite eggs and fecal coliforms, and slow rate infiltration (SRI) and rapid infiltration (RI) systems. The latter two systems, however, transport their purified effluent to the groundwater, where it normally must be pumped back to the surface for irrigation use. A stabilization pond system can also be upgraded by a floating aquatic plant system in the same manner as the FWS constructed wetland. Such a system will, however, significantly increase operational requirements [20].

ISFs are capable of meeting the parasite and fecal coliforms criteria, but the recirculating sand filters (RSF) have not yet been shown to do so. The latter are more compact and capable of significant nitrogen removal but require mechanical equipment in the form of pumps. Subsurface soil infiltration (SWIS), SRI, and RI systems can also meet the criteria, but will require pumping energy, since all three transport their effluents to the groundwater. Potential cost-effective alternatives which accomplish the example treatment task by providing reusable water at the surface without the need for electrical equipment are as follows:

1. Stabilization ponds + FWS constructed wetland
2. Anaerobic (high rate) ponds + ISF
3. Imhoff tanks + ISF

Analysis of the above appropriate treatment technology systems in greater depth can assist future designers of urban community wastewater systems to understand some of the tradeoffs and areas of uncertainty. Among the issues which may sway the choice of treatment systems are performance, reliability, area requirements, capital and construction costs, and socioeconomic issues.

Area requirements for these systems to treat 100 m^3/day of wastewater are estimated and reported in Table 1.

Table 1 Area required for the three systems

System	Area required (m^2)
Stabilization ponds + FWS constructed wetland	13,300
Anaerobic (high rate) ponds + ISF	1,950
Imhoff tanks + ISF	1,850

Source: [20]

Both filter-based systems require only a small fraction (about 15%) of the area required for the pond/constructed wetland system. Even if one were to accept the conclusion that a series of ponds can meet unrestricted irrigation standards, the area requirement is still about seven times that required by the ISF systems.

Traditional criteria used for pond design are not normally of great importance in water-short areas like North Africa, since ponds are designed for BOD removal, not fecal coliforms or parasitic egg removal, and the removal of fecal coliforms and nematode eggs controls the design. Only when a wastewater has a very high BOD (800 mg/l or more), BOD removal model should be considered. Since the removal of pathogens is a time-related relationship, substitution of a FWS constructed wetland for some of the maturation-pond time required in the lagoon system should be feasible; however, no studies have yet determined exactly what the equivalency ratio is.

To meet WHO standards, the total required retention times for a typical stabilization pond-treated influent and for different parameters at 20°C are reported in Table 2.

In summarizing the options for an urban community, the choice of treatment for ultimate reuse will hinge on the following:

- *Reuse requirements*. If the reused wastewater is to be used for vegetables, citrus, or other crops to be eaten raw, the options using stabilization ponds and intermittent filters can be used, or a recirculating filter may be substituted with subsurface drip irrigation only. This last restriction may be lifted if it can be proven that the RSF effluent is free of nematode eggs, or if disinfection of the effluent is used.
- *Land availability*. If sufficient land is available, the other limitations stated above and below will control the options evaluated. If land availability is limited by economics or terrain or surrounding development, one of the filter options should be chosen.
- *Operational capability*. If a sufficiently skilled management program with electricity is available, all options are possible. If, as is often the case, only unskilled labor is locally available, only the pond-wetland or anaerobic lagoon-intermittent filter options are viable (Table 3).

Finally, when the viable options which pass the above tests are evaluated against each other, experience in the Mediterranean countries has shown that they are very similar in present worth cost, so local availability or cost of components, climatic and social conditions, and support infrastructure may be the deciding factor between them. For example, the lack of suitable sand or substitute media locally

Table 2 Required retention times for different parameters regarding WHO standards

Parameter	Days	Reference
BOD, mg/l	5	[21]
Fecal coli, per 100 ml	16	[22]
Nematode eggs, per liter	18	[23]

Source: [20]

Table 3 Comparison of the two passive alternative technologies

	Lagoon-wetland	Anaerobic lagoon-ISF
Land requirement, m^2	13,000	2,000
Energy KWH/day	0	0
Capital cost, US$	200,000	150,000
	250,000	200,000
O&M cost, US$/year	5,000–7,000	7,000–10,000
Effluent quality		
BOD_5 (in = 200), mg/l	10	5
TSS (in = 100), mg/l	10	5
TN (in = 50), mg/l	10–35	35–40
TP (in = 10), mg/l	7–8	7–9
FC (in = 10^6), per 100 ml	10^2–10^3	10^1–10^2
Virus (in = 10^3), per liter	10^1–10^2	0–10
Parasite ova (in = 10^3), per liter	0–10	0

Source: [20]

will significantly increase the cost of the filter options. Very close proximity of housing to the treatment site may make odors concerns a key issue and add costs to certain options to control odors. Therefore, engineering decisions of which method of treatment or sitting of the facility may be skewed to suit local needs. However, in all cases the appropriate technology options presented herein are significantly more sustainable than the use of sophisticated urban wastewater treatment technologies such as activated sludge with tertiary treatment for urban communities of Southern Mediterranean region.

4 Economic and Financial Aspects

The financing of the projects concerning the construction of a processing plant constitutes the main handicap facing the realization of these projects. The communes, using state credits, finance most of the wastewater projects. Other plants have been built as pilot plants, within the framework of partnership gathering water distribution control services of the municipality. The financial contribution of International Organizations also helps in the construction of small plants in some cities and some small communes of Morocco. Although the communes have proved to be willing to work, the conception of a project on processing plant goes first through setting a draining network. The cost of financing the latter makes the future projects of processing plants seem illusory.

The costs of investing in wastewaters vary considerably following the adopted technology, the processing chain, and the specificities of the site, the polluting charge, and the future of treated wastewaters. For the processed waters directed to reuse, the standards of health and environment protection impose a quality of the final effluent and the final use of the treated wastewater. Still, it is possible to compare the costs of investment of different projects and the reuse of wastewaters

Table 4 Costs of different wastewaters treatment plants in Morocco

Plant	Capital investment cost (millions of Dirham)	Running cost (Dirham/year)*	Cost per inhabitant/ (Dirham/year)*	Cost/m^3 (Dirham/year)*
Ouarzazate	5	108.500	643	1,43
Ben Sergao	5	307.500	250	1,12
Benslimane	96,44	935.000	1.928	1,45
Drarga	20,3	260.000	1.000	1,70

*1 Euro = 10 Dirham

in Morocco per equivalent inhabitant. Table 4 sums up the costs of the capital investment and running cost of the projects of Ouarzazate, Ben Sergao, Benslimane, and Drarga.

Until now, there is no model of cost estimation of wastewater treatment in the Moroccan context. As mentioned above, these costs vary according to a number of factors. However, the leading experiences have shown that the cost of appropriated technologies for Morocco such as lagoon and infiltration-percolation varies between 1,12 and 1,70 Dirham/m^3 of treated waters.

In the case of the projects of Drarga and Benslimane, the treated wastewaters are sold (for the golf course in Benslimane and to farmers in the case of Drarga). In Benslimane, the treated wastewaters are sold to the golf for 2 Dirham/m^3, while the initial tariff in Drarga is 0,50 Dirham/m^3. For more comparison, the agricultural wastewaters distributed by the Department of Agriculture are sold for an average tariff of 0.5 Dirham/m^3, while the price of potable water varies between 2 and 8 Dirham/m^3. It is worth noting that in many places, farmers directly pump underground waters and pay the cost of pumping solely. In some regions where ground level of the aquifer has witnessed a considerable decrease, especially in Souss Massa, the pumping cost has become very expensive and may raise up to 1.5 Dirham/m^3.

5 Concluding Remarks and Recommendations

Domestic treated wastewater to be reused is one tool to address the food and water insecurity facing many countries in the Southern Mediterranean region. In coming years, in most of these countries, valuable fresh water will have to be preserved solely for drinking, for very high value industrial purposes, and for high value fresh vegetable crops consumed raw. Where feasible, most crops in arid countries will have to be grown increasingly, and eventually solely, with treated wastewater. The economic, social, and environmental benefits of such an approach are clear. To help the gradual and coherent introduction of such a policy, which protects the environment and public health, governments shall have to adapt an Integrated Water Management approach, facilitate public participation, disseminate existing knowledge, generate new knowledge, and monitor and enforce standards.

To ensure the sustainability of the system, a cost recovery analysis should not be neglected. As the income of most farmers is low, it is not realistic to expect farmers to pay any portion of the treatment cost, but tariffs should cover the cost of transferring and distribution of the reclaimed water

The quality of effluents, which can be achieved, is mainly related to a particular treatment technology, together with the quantity produced. In most of the Southern Mediterranean countries, number and capacities of existing WWTPs are far from meeting the requirements. Most of the plants need extension, rehabilitation, or upgrading, and in some cases, new facilities need to be constructed. This is the case in both urban and rural areas, even though potential solutions are different. In urban areas, emphasis has to be put on large, central WWTPs with more sophisticated technology, whereas in rural areas decentralized, low-tech, and low cost facilities are required, possibly promoted by means of a "Municipal Fund."

On the technology side, small-scale decentralized sanitation technology, such as lagoons, sand filters, constructed wetland, and even septic tanks combined with small-bore sewers, offers great potential in small rural areas. As far as irrigation technologies are concerned, bubbler irrigation may be considered the preferred method of application particularly for tree crops. It provides some water savings and also some degree of protection against clogging and contamination exposure.

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Overview of New Practices in the Reclaimed Water Reuses in the Mediterranean Countries

Faycel Chenini

Abstract Themes object of this chapter concern wastewater reuse in the Mediterranean region where the problem of water scarcity is continuously aggravating: while the renewable water resources decrease, the demand for potable water is increasing due to population growth and increasing economic activities. One of the most important future options for a sustainable management of water resources in the Mediterranean is the reuse of treated wastewater. Wastewater reuse management is one of the challenges that all Mediterranean countries will have to deal with in the coming decades. Therefore, these countries need water strategies that have to take into account alternative measures to cope with this situation. Wastewater reuse is one of the essential options for Mediterranean countries for the development of their national water policies and strategies.

The innovative approach is actually not a question any more of extracting waste to obtain reusable water, but of extracting reusable water for then using the value elements contained in “waste.” Therefore treated wastewater became a resource. Water extracted initially could be used at various applications, such as the irrigated agricultural, landscape irrigation or the production of drinking water, according to terms of references indicated by the end users.

The extraction of the value elements mainly relates to carbon, nitrogen, phosphorus and sulfur. The value of these elements lies mainly in the biopolymers and energy production, being used in particular for plastic manufacture, using carbon. The nitrogen or phosphorus could also be used like fertilizers. As for reusable water, the extraction of these various elements will have to follow terms of references fixed by the end users.

The remaining fraction, after extraction of reusable water and the value elements, is not very significant and will be the subject of a specialized treatment (Angelakis in Water Res 33(10):2201–2217, 1999).

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This chapter will give a critical overview of new practices in the reuse treated wastewater and sludge in the Mediterranean.

Keywords Mediterranean countries, Practices, Reuse, Treated wastewater

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Abbreviations

EC Directive	European Commission
MSW	Municipal solid waste
TDS	Total dissolved solids

1 Introduction

In the world, more than 368 km^3 of waste water are collected annually, only 160 km^3 are treated before rejection in the natural environment and 7.1 km^3 are reused. Till 2015, the world capacities for reusing treated wastewater will reach 20 km^3 per year. Because of the unwilling of the consumers and important needs related to certain activities, water resulting from treatment plants is generally used by industry and for the irrigated agriculture and landscaping irrigation. However, by adding some additional treatments to this resource, water becomes drinkable and usable for food. Several countries have already adopted this system (i.e., reused treated wastewater represents 1% of the drinking water reservoirs of Singapore city and 35% of water consumption of the inhabitants of the Namibian capital Windhoek). This technology as a future for the driest countries finds its limits in respect of the energy consumption and the production of waste. The high costs of the installation and the operation of these infrastructures can also represent an obstacle but remain lower than other alternatives like desalination.

The reuse of wastewater can also be used in industrial networks with industrial ecology logic.

Joint production of drinking water, energy, and other valuable elements from wastewater, and the innovating processes of treatment belong subjects of research in progress in this field.

The current trend is related to the intensification of wastewater reuse: it can be used two or three times before being rejected into the natural environment. The treatment and the reuse of wastewater resources are the key components of the water management regarding their economic and ecological advantages. Indeed wastewater recycling is twice less expensive than the desalination of sea water. In spite of the reduction of the cost of this technology, the difference between these two solutions is still maintained because of simultaneous progress of recycling [11].

Among terms often utilized, wastewater or sewage is water that have been used for various purposes around the community and that has been adversely affected in quality. It contains liquid waste discharged by domestic residences, commercial properties, industry, and/or agriculture and can include a wide range of potential contaminants. This is raw or untreated wastewater. When untreated, wastewater leads to serious impacts on the environment and on the health of people. Pathogens can cause a variety of illnesses. Some chemicals pose risks even at very low concentrations and can remain a threat for long term because of bioaccumulation in animal or human tissue. Wastewater could be treated or partially treated to improve its quality before it is discharged into receiving milieu or used. Treatment may be natural or artificial purification processes. Industrial effluents containing high levels of heavy metals or other chemical or organic constituents must be considered separately because they require specific treatments.

There are numerous processes that can be used to clean up wastewater depending on the type and extent of contamination. Most wastewater is treated in wastewater treatment plants which may include physical, chemical and biological treatment processes. According to the reuse, treatment process could be more or less advanced.

The use of wastewater, whether raw or treated, may not be socially desirable due to the odor, the nuisance, and social attitudes, but may be socially tolerated as long as there are beneficial uses for it especially when it can be used to generate economic activity and support livelihoods [1].

2 Overview of New Practices in the Reuse of Treated Wastewater

2.1 Treated Wastewater Reuse for Agricultural and Landscape Irrigation

2.1.1 Problems and Needs

Because of the nature of sewage, fears have expressed about the possible hazards associated with effluent reuse. In assessing these hazards, various pathways for the dissemination of undesirable pollutants have been examined. Two aspects of wastewater reuse in agriculture have become subjects of paramount importance: the possible risks to health and the potential environmental damages. Health considerations are centered around the pathogenic organisms that are, or could be, present in the effluent and the build-up of toxic materials within the soil, and subsequently within plant and animal tissues which might eventually reach the human food chain. The leaching of materials such as nitrates and toxic soluble chemicals into the groundwater is also a matter for concern. Environmental risks involve the effects of the use wastewater containing dissolved substances which have deleterious effects on the growth and development of plants.The reuse of treated wastewater for agriculture irrigation has some advantages as well as some disadvantages.

Advantages include:

- Source of additional irrigation water.
- Savings of high quality water for other beneficial uses.
- Low-cost source of water supply.
- Economical way to dispose of wastewater and prevent pollution and sanitary problems.
- Reliable, constant water source.
- Effective use of plant nutrients contained in the wastewater, such as nitrogen and phosphorus.
- Provides additional treatment of the wastewater before being recharged to groundwater.

Disadvantages include:

- Wastewater not properly treated can create potential public health problems.
- Potential chemical contamination of the groundwater.
- Some of the soluble constituents in the wastewater could be present at concentrations toxics to plants.
- The treated wastewater could contain suspended solids at levels that may plug nozzles in the irrigation distribution system as well as clog the capillary pores in the soil.
- The treated wastewater supply is continuous throughout the year while the demand for irrigation water is seasonal.
- Major investment in land and equipment.

Regulations, guidelines, and criteria have been developed for the use of treated wastewater for agricultural irrigation and are generally based on the following parameters:

- For farm workers and public health protection, the treated water must pose no bacteriological or virological hazard.
- Salinity (total dissolved solids or TDS) must be low enough to maintain favorable osmotic pressures for plants to take up water.
- Certain ions making up TDS, such as boron, chlorides, and sodium must not be of levels harmful to crops, and sodium must not be at levels harmful to soils.
- Trace levels of certain metals and synthetic organics must be controlled such that crop growth is not adversely affected.
- Concentrations of other heavy metals, such as molybdenum and possibly cadmium, must not be high enough in plants to be toxic to animals eating the plants (which themselves might be unaffected by the substance).
- Suspended solids, chemical precipitates, and algae growth must be controlled to prevent clogging of spray nozzles and drip applications of irrigation units [2].

2.1.2 Quality Impacts and Achievement of Wider Effects

Several components in the water used for agriculture irrigation are of particular importance and include salinity, exchangeable ions (Na, Ca, and Mg), boron, and trace metals (Cd, Cr, Cu, Hg, Ni, Mo, Pb, and Zn).

Salinity and exchangeable ions are the most important parameters in determining the suitability of conventional or marginal water for agriculture irrigation. Treated wastewater is characterized by Boron and trace metals as specific toxic parameters.

Boron and Treated Wastewater Reuse

The most current toxicity problem for crops irrigated with treated wastewater is from boron. The source of boron in wastewater is usually from household detergents containing per borate – the bleaching component in the detergent.

Boron can accumulate in the upper soil layers in arid regions to levels that are toxic to plants. The amount of boron available to plants in soil is pH dependent. Maximum born adsorption by soil has been found to be at pH 9. Boron toxicity in plants is often associated with arid or semiarid regions where boron levels are frequently high in soil.

The toxicity problems for boron can occur at levels down to 0.5 mg/L. Certain management practices can be used to reduce the toxic effects of boron. These management practices include:

- Irrigate more frequently.
- Use additional water for leaching.
- Change or blend water supplies.
- Plant less sensitive crops.
- Use additional nitrogen to maximize fertility of the soil for growth of a crop such as citrus.

Salinity and Treated Wastewater Reuse

Salinity is defined as the total solids in a water sample after all carbonates have been converted to oxides, all bromides and iodides have been replaced by chlorides, and all organic matter has been oxidized, and is a measure of the concentration of dissolved mineral.

The extent of salt accumulation in the soil depends on the concentration of salts in the irrigation water and the rate at which it is removed by leaching.

The deleterious effects of salinity can be augmented by a soil with poor drainage characteristics, high evapotranspiration rates, and the type of crop being grown.

The only suitable way to control a salinity problem is by applying more irrigation water than can be used by the plant and in this way provide excess water that leaches throughout the plant's root zone and carries off excess salt and thus maintains a soil salt concentration at an appropriate level.

Exchangeable Cations and Treated Wastewater Reuse

The concentration of sodium, calcium, and magnesium ions in treated wastewater used for agricultural irrigation must be considered. High sodium concentrations not only reduce the clay-bearing soil's permeability, but also affect the soil structure. When calcium is the predominant cation adsorbed in the exchangeable soil complex, the soil tends to have a granular structure and is easily worked and readily permeable. When sodium concentrations are high the clay particles are dispersed and the soil permeability is reduced.

Trace Metals and Treated Wastewater Reuse

All wastewaters delivered to treatment facilities contain trace metals or elements. Industrial plants are an obvious source, but wastewaters from private residences can also have high trace metal concentrations. Some are essential for plant and animal growth, but all can become toxic at elevated concentrations. The most important trace metals in wastewater include cadmium, chromium, copper, mercury, molybdenum, nickel, lead, and zinc.

Trace metal concentrations in waste water are affected by their sources and the wastewater treatment processes provided. The concentration of trace metals in treated wastewater are important in land application situations because they may shorten the lifetime of the site through the accumulation of one metal or a combination of metals in excess of the biological toxicity threshold [12].

However, advanced waste water treatment processes such as chemical coagulation and carbon adsorption can in most cases remove over 90% of the trace metals from the influent wastewater. A few of the trace metals in wastewater are essential for life, and when applied may enrich the soil. Zinc is the metal most likely to provide an environmental benefit. Large areas of land have too little zinc for the growth of some crops and also the average dietary zinc intake by humans is marginal. Nevertheless, such essential-to-life metals (and other nutrients too) can accumulate and pose potential long-term [3].

2.1.3 Category of Reuse

Agricultural and landscape irrigation include: crop irrigation, commercial nurseries, parks, school yards, freeway medians, golf courses, cemeteries, greenbelts, and residential areas.

2.1.4 Potential Constraints

Potential constraints include: Effects of salts on soils and crops, Public health concerns, surface and groundwater pollution, marketability of crops, and public acceptance.

2.2 Treated Wastewater Reuse for Groundwater Recharge

2.2.1 Problems and Needs

The purposes of groundwater recharge using treated wastewater can be:

- To establish saltwater intrusion barriers in coastal aquifers.
- To provide further treatment for future reuse.
- To augment potable or non-potable aquifers.
- To provide storage of treated water or to control or prevent ground subsidence.

There are three methods used for groundwater recharge utilizing treated wastewater:

- Surface spreading or percolation and infiltration.
- Direct injection.
- River bank or stream infiltration as a result of streamflow augmentation.

In surface spreading, treated waste water percolation and infiltration through the unsaturated zone takes advantage of the subsoil's natural ability for biodegradation and filtration, thus providing additional in situ treatment of the wastewater and additional treatment reliability to the overall wastewater management system. Another advantage of ground water recharge by surface spreading is that it can be carried out in the vicinity of metropolitan and agricultural areas and thus counteract falling groundwater tables.

Also, groundwater recharge helps provide a loss of identity between treated water and ground water.

This loss of identity has a positive psychological impact where reuse is contemplated and is an important factor in making treated water acceptable for a wide variety of uses, including potable water supply augmentation.

In direct injection, treated wastewater is pumped under pressure directly into the groundwater zone, usually into a well-confined aquifer. Groundwater recharge by direct injection is practiced, in most cases, where groundwater is deep or where the topography or existing land use makes surface spreading impractical or too expensive. This method of groundwater recharge is particularly effective in creating freshwater barriers in coastal aquifers against intrusion of saltwater. Both in surface spreading and in direct injection, locating the extraction wells at as great a distance as possible from the spreading basins or the injection wells increases the flow path length and residence time of the recharged groundwater, as well as the mixing of the recharged water and the other aquifer contents.

River bank or stream bed infiltration is a means of indirect groundwater recharge and is widely practiced in Europe. Here, groundwater recharge may be used as a treatment scheme in water supply systems where the source is a surface water contaminated by substantial discharges of industrial and municipal wastewater.

The contaminated water percolates not only from the riverbank or streambanks but also from spreading basins to an aquifer and then travels through the aquifer to extraction wells, some distance from the source.

In some cases, the residence time underground is only 20–30 days, and there is almost no dilution by natural groundwater.

There are four major water quality factors to be considered in groundwater recharge with treated wastewater:

- Pathogens
- Total minerals
- Heavy metals
- Stable organic substances

Effluent quality guidelines or criteria are generally more stringent for direct injection than for land spreading. The reason for the more stringent quality requirements is that there is no added protection using direct injection because the water enters the aquifer directly without percolating or filtering through the soil above the aquifer. The water quality requirements vary from region to region depending on the existing groundwater quality and its usage [4].

2.2.2 Category of Reuse

Aquifer recharge categories of treated wastewater reuse can be considered as following: groundwater replenishment, salt water intrusion, and subsidence control.

2.2.3 Potential Constraints

Potential constraints are limited to potential toxicity of chemicals and pathogens.

2.3 Treated Wastewater for Direct and Indirect Potable Reuse

2.3.1 Problems and Needs

Direct reuse of wastewater for potable purposes (i.e., Chanute, Kansas and Windhoek, South Africa) is clearly limited, indirect reuse for potable purposes takes place constantly and on a worldwide basis. The flows in such rivers as the Rhine, Thames, and Ohio are anywhere from 20 to 50% urban and industrial wastewater and these rivers are the water supply source for many large cities. Other examples of indirect reuse of wastewater for potable use in the U.S. is at Whittier Narrows, CA; El Paso, TX; and Occoguan, VA. Indirect potable reuse is more acceptable to the public than direct potable reuse as the water loses its identity as it moves through a river, lake, or aquifer. Indirect reuse, by virtue of the residence time in the water course, reservoir, or aquifer, often provides additional treatment and offers an opportunity for monitoring the quality and taking appropriate measures before the water is ready for distribution. In some instances, however, water quality may actually be degraded as it passes through the environment.

2.3.2 Category of Reuse

Blending in water supply and pipe-to-pipe water supply are the two categories of treated wastewater reuse for potable water.

2.3.3 Potential Constraints

Potentially toxic chemicals, public health, and public acceptance are the potential constraints for using treated wastewater for potable purposes.

2.4 Treated Wastewater for Non-Potable Urban Reuse

2.4.1 Category of Reuse

Fire protection, air conditioning and toilet flushing can be considered as the main treated wastewater for non-potable urban purposes.

2.4.2 Potential Constraints

Potential constraints are: Public health, fouling, scaling, corrosion, and biological growth.

2.5 Treated Wastewater for Industrial Reuse

2.5.1 Problems and Needs

Industry represents an important potential market for reuse of treated wastewater. Industry can recycle their water within the plant such as is done in the steel mills, breweries, electronics plants, and chemical mineral processing, and in this way conserve water as well as avoid stringent industrial effluent standards and regulations. The in-plant recycling processes will not be covered here as this is a complete field in itself.

The major factors that influence an industry in using treated waste water is the availability of the water, the industry's discharge requirements, water quality, volume, economics, and reliability.

The major industrial categories that use treated wastewater include: Evaporative cooling water, Boiler feedwater, Process water, and Irrigation and maintenance of plant grounds, fire protection, and dust control.

Water quality criteria, standards, guidelines and requirements vary from industry to industry as well as within a single industry. Specific water quality requirements for many industries have not been established but possible detrimental effects of various components in the treated waste water on specific processes and equipment must be taken into account.

Of the various industrial users of treated wastewater, cooling water is currently the biggest single application. The cooling water can be a once-through cooling operation or a recirculating cooling system using towers, cooling ponds, or lakes.

Quality requirements for cooling water are related to three common problems: scaling, corrosion, and biofouling. Scale-forming constituents found in effluent include calcium carbonate and calcium phosphate. Constituents in effluent known to cause corrosion are total dissolved solids, including chlorides and ammonia. Ammonia is particularly corrosive to copper alloys commonly used in heat exchange systems. Nutrients in effluent, such as nitrogen and phosphorus, are known to cause biofouling [5].

2.5.2 Category of Reuse

Treated wastewater can be reused for the industrial sector as cooling, boiler feed, process water, and heavy construction.

2.5.3 Potential Constraints

Scaling, corrosion, biological growth, and fouling and public health concerns are the main constraints facing the reuse of treated wastewater.

2.6 Treated Wastewater for Recreational and Environmental Reuse

2.6.1 Problems and Needs

When treated water is to be employed for recreational use specific criteria, standards, and guidelines may be formulated given the particular use and the degree of physical contact experienced by the user as well as the secondary pollutional sources. The sources of the secondary pollutants in recreational areas, such as bathing places, may include:

- Body discharges such as the mucous from the nose, saliva, sweat, traces of fecal matter, urine, dead skin, etc.
- Air contaminants such as dust, pollens, particulate matter, etc.
- Street and work-area soil which accumulates on the skin.
- Different body creams, ointments, oils, lotions, etc.
- Sewage from domestic, industrial, commercial, institutional, recreation places, hotels, municipal works, etc.
- Cultivated fields, farms, etc.
- Animals.

The criteria, standards, or guidelines for treated water to be used for recreational purposes can be subdivided into the following three classes:

1. *Elementary Body-Contact Recreational Water*: This class of treated water includes water utilized for boating, canoeing, camping, fishing, and landscape and golf course The treated water used for contact recreational applications include swimming, bathing, waterskiing, etc. This class addresses the situations where there is intimate and prolonged contact between the individual and the

water and where there is a great risk of ingesting a large quantity of water which may impose a health threat.
The routes of transmission of viruses may occur due to ingestion of water, or via the exposed mucous membranes and breaks in the protective skin barrier. Swimming pools have been implicated as the source of adenovirus conjunctivitis and pharyngitis, as well as enterovirus meningitis.
Usually, the criteria, standards, or guidelines that are required for this class of reuse are more stringent than those required for non-body contact sports. Treated wastewater requirements include:
Treated water needs to be esthetically attractive.

- The water used must have an acceptable physical quality; this is to be established through the control of parameters such as color, taste, odor, temperature, solids concentration, and turbidity.
- Treated water must be free of toxic compounds and other harmful chemical substances. For example, the treated water must have an acceptable pH level. The pH can range from 6.5 to 8.3. The lacrimal fluid of the human eye has a pH of around 7. The deviation of the pH of the treated water from the normal value may result in irritation to the eyes.
- The treated water must be hygienically safe and free from disease-causing agents.

2. *Secondary Body-Contact Recreational Water*: This class of treated water includes water utilized for boating, canoeing, camping, fishing, and landscape and golf course irrigation. The quality requirement for this category of reuse is less strict than for elementary body contact.
3. *Non-Contact Recreational Water*: The treated water used in situations where there is no intimate contact between the human body and the water signifies this subdivision. It includes recreational confined water bodies, fountains, aquaculture, etc. The most significant quality criteria that need to be considered include:

- The furnishing of a reasonable temperature to sustain aquatic life.
- The supply of a suitable concentration of dissolved oxygen.
- The provision of suitable chemical quality aspects with respect to the concentration of trace elements, acidity, alkalinity, pH, pesticides, insecticides, biotoxins, toxic substances, and radionuclides.
- The elimination of nutrients to avoid the development of eutrophic conditions.
- The supply of treated water with reasonable microbiological quality [6].

2.6.2 Category of Reuse

Different categories of treated wastewater for environment and recreational reuse include: lakes and ponds, marsh enhancement, streamflow augmentation, fisheries, and snowmaking.

2.6.3 Potential Constraints

Health concerns and eutrophication are the potential constraints.

2.7 Treated Wastewater for Reuse in Aquatic Environments

2.7.1 Problems and Needs

The introduction of treated water to augment flow in rivers and streams can have an impact on the aquatic life. Usually, the water quality in a river or stream is related directly to the quantity of its flow. Generally, the greater the stream flow the more pollutants it may incorporate without violating the water quality standards.

When water quality is managed through control of the concentration of the input waste, the degree of needed treatment ought to be indicated. The required treatment must be as economical and efficient as possible. To accomplish these requirements, the limits for pollutants in receiving water courses must be carefully defined.

2.7.2 Potential Constraints

The basis of the limits first, should be the public health of the community, and second, the environmental health of biological systems within the receiving water.

Discharge of pollutants to surface waters should be controlled if they contain wastes that will:

- Settle or form objectionable deposits.
- Float or form objectionable debris, oil scum, and other matter.
- Present objectionable color, odor, taste, and turbidity.
- Produce undesirable physiological responses in man, fish, and other aquatic life. These materials include radionuclides and toxic substances.

2.8 Treated Wastewater Reuse for Livestock and Wildlife Purposes

2.8.1 Problems and Needs

The most important parameter of concern with livestock drinking treated water is salinity. The salts of most concern related to water's salinity include calcium, magnesium, sodium, sulfates, bicarbonates, and chlorides. Water with a high salinity can cause physiological problems and even death for livestock due to an osmotic imbalance. Total dissolved solids of 1,000 mg/L (electrical conductivity of 1.5 mmohs/cm or less) is considered safe for both livestock and cattle. Several countries do have proposed regulations governing the watering of non-dairy livestock as well as regulations regarding washing of non-dairy livestock [7].

2.8.2 Potential Constraints

Public and animal health concerns are the potential constraints.

3 Overview of New Practices in the Reuse of Sewage Sludge

3.1 Sewage Sludge Reuse for Agriculture

Most wastewater treatment processes produce a sludge which has to be disposed of. The reuse of sludge on agriculture has beneficial plant nutrients. Sewage sludge also contains pathogenic bacteria, viruses, and protozoa along with other parasitic helminthes which can give rise to potential hazards to the health of humans, animals, and plants. Thus sewage sludge will contain, in addition to organic waste material, traces of many pollutants used in our modern society. Some of these substances can be phytotoxic and some toxic to humans and/or animals; so it is necessary to control the concentrations in the soil of potentially toxic elements and their rate of application to the soil. Apart from those components of concern, sewage sludge also contains useful concentrations of nitrogen, phosphorus, and organic matter. The availability of the phosphorus content in the year of application is about 50% and is independent of any prior sludge treatment. Nitrogen availability is more dependent on sludge treatment, untreated liquid sludge and dewatered treated sludge releasing nitrogen slowly with the benefits to crops being realized over a relatively long period. Liquid anaerobically-digested sludge has high ammonia-nitrogen content which is readily available to plants and can be of particular benefit to grassland. The organic matter in sludge can improve the water retaining capacity and structure of some soils, especially when applied in the form of dewatered sludge cake.

3.2 Sewage Sludge Reuse for Biogaz Production

Sewage sludge, a precipitated solid matter gotten from the treatment of wastewater can be further treated to generate a gas (sludge gas). This is a type of biogas which is produced from the anaerobic digestion of the organic substance sludge, which can serve as a superior alternative to composting such type of biomass. The biogas consists of about 60–70% of methane and 30–40% of carbon dioxide. This composition makes it highly suitable for combustion in gas engines to generate thermal energy for heating the sludge, offsetting other heating requirements, and generating electricity.

3.3 Sewage Sludge Reuse for Co-Incineration and Co-Firing

Wastewater treatment plant sludge generally has a high water content and in some cases, fairly high levels of inert materials. As a result, its net fuel value is often low. If sludge is combined with other combustible materials in a co-incineration scheme, a furnace feed can be created that has both a low water concentration and a heat value high enough to sustain combustion with little or no supplemental fuel.

Virtually any material that can be burned can be combined with sludge in a co-incineration process. Common materials for co-combustion are coal, municipal solid waste (MSW), wood waste and agriculture waste.

There are two basic approaches to combusting sludge with MSW: (1) use of MSW combustion technology by adding dewatered or dried sludge to the MSW combustion unit and (2) use of sludge combustion technology by adding processed MSW as a supplemental fuel to the sludge furnace. With the latter, MSW is processed by removing non-combustibles, shredding, air classifying, and screening. Waste that is more finely processed is less likely to cause problems such as severe erosion of the hearths, poor temperature control, and refractory failures.

3.4 Biosolids Production

Biosolids have a negative image as they are associated with sludge, and therefore there is psychological resistance to its use. In order to sell the product, it has to be presented in such a way to allow a positive image to be associated with it.

It is a material which is very valuable and rich in nutrients; a prevention at source and an in-depth treatment in order to ensure that it is free of dangerous products for the environment and health (microbes and micropolluters control) has to be carried out, but it is quite interesting in terms of potential uses.

Four main uses for biosolids:

- Dryland wheat (45%)
- Canola and hops (25%)
- Private and public forests (25%)
- GroCo compost (5%)

Biosolids are extremely valuable because they enrich the soil (humic matter and nutrients), prevent erosion, and add moisture to soils because they retain water and improve the structure. They are much more effective than conventional fertilizers in the increasing of agricultural production, a fact which by now has been thoroughly demonstrated by many studies [8].

3.5 Sewage Sludge Composting

Composting is an alternative which is considered an ecological component of the integrated sewage sludge management. It consists in an aerobic biodegradation of organic materials. This biochemical decomposition is achieved by a diversity of micro-organisms. The resulting product, called compost, is rich in humus substances. The composting process is both a consumer and a producer of heat. The biodegradation generates a water loss, a CO_2 production. It balances itself by a reduction of volume that can reach 50% of initial volume of sludge initially put in the composting pile. The finished composts rich in humus substances and consequently is an excellent product for soil organic amendment. It permits to improve soil properties and to gradually provide nutrients to crops.

Composting is characterized by three categories of parameters:

- Starting parameters: C/N of organic materials, moisture content, particle size, pile dimension.
- Monitoring parameters of the composting process: moisture content, temperature and oxygen (aeration).
- Quality parameters of the finished compost.

4 Public Perception of and Attitudes to Treated Wastewater and Sludge Reuse

Any successful reuse of wastewater and sludge for any purposes must consider the overall perceptions of, and attitudes to such case, both by people in the areas being considered, and also by the officials in appropriate institutions and regulatory agencies. The perceptions generally may have both short-term and long-term implications. For example, there may-be deep-rooted sociocultural barriers to treated wastewater and sludge reuse, which can only be overcome by pilot or small-scale projects, which can demonstrate over a few seasons that reuse of wastewater and sludge for irrigation are an economically attractive proposition for farmers, since it could visibly increase their production, and hence income, and that such practices do not have any discernable health risks.

The attitudes of the people in the area will also depend on their perceptions of potential risks from such treated wastewater and sludge reuse. This, in turn, will depend on the probability of occurrence of any health hazard, the magnitude of that hazard, and how that hazard relates to them. If through an objective information campaign it could be pointed out to the farmers that there are not documented cases of health hazards found anywhere in the world through restricted irrigation by treated wastewater, the initial reservations are likely to be overcome within a period of 1–5 years.

It is also important to note the perception of health and environmental associated risks of treated wastewater and sludge reuse by the national and governmental institutions which have specific responsibilities in these areas. Because of differing perceptions of risks, socio-economic conditions, political implications and lack of reliable data on cause-effect relationships, different countries have taken different regulatory approaches with varying standards to manage the reuse of treated wastewater and sludge. This is an area where there is unlikely to be a universal standard in the foreseeable future. It would be desirable for each Mediterranean country to develop its own regulations, which would satisfy its own set of conditions in the frame of Regional Mediterranean agreement [9].

5 Impacts and Achievement of Wider Effects of the Reuse

The natural background concentration of metals in the soil is normally less available for crop uptake and hence less hazardous than metals introduced through sewage sludge applications. Research carried out in some countries has shown that the amounts of Cd, Ni, Cu, Zn, and Pb applied in liquid sludge at three experimental sites could be accounted for by soil profile analyses 5 years after sludge applications, with the exception of Cu and Zn applied to a calcareous loam soil. These field experiments also determined the extent of transfer of metals from sludge-treated soil into the leaves and edible parts of different crops of major importance Mediterranean agriculture and the effect of metals on yields of these crops. Although all the plots received sufficient inorganic fertilizer to meet crop requirements for nutrients, the applications of sludge had some effects on crop yields. In 60% of the cases studied, crop yields were not significantly affected but in 26% of the cases liquid sludge application resulted in significantly increased crop yields, attributed to the beneficial effects on soil structure. Reductions in wheat grain yield, from 6–10%, were noted on the clay and calcareous loam soils treated with liquid sludge and the sandy loam and clay soils treated with bed-dried sludge. However, this yield reduction was not thought to be due to metals but the most likely explanation was lodging of the crop as a result of excessive nitrogen in the soil.

Increases in metal concentrations in the soil due to sludge applications produced significant increases in Cd, Ni, Cu, and Zn concentrations in the edible portion of most of the crops grown: wheat, potato, lettuce, red beet, cabbage, and ryegrass. In most cases, there was no significant increase of Pb in crop tissue in relation to Pb in the soil from sludge application, suggesting that lead is relatively unavailable to crops from the soil. The availability of metals to crops was found to be lower in soil treated with bed-dried sludge cake compared with liquid sludge, the extent being dependent on the crop. Even though the Ni, Cu, and Zn concentrations in the soils treated with high rates of application of liquid and bed-dried sludges were close to the maximum levels set out in the EC Directive, no phytotoxic effects of metals were evident, with one exception. This was in lettuce grown on clay soil, when Cu and Zn levels exceeded upper critical concentrations at high rates of sludge application [10].

6 Conclusion and Recommendations

Water has always been used and reused by man. The natural water cycle – evaporation and precipitation – is one of reuse. Cities draw water from surface streams and discharge waste into the same streams, which in turn become the water supplies for downstream users. In the past, dilution and natural purification were usually sufficient to allow such a system to be satisfactory, but in recent years, population and industrial growth have meant that wastewater must be treated before its discharge to maintain the quality of streams. Treated wastewater is now considered an additional water resource.

As a substitute for freshwater in irrigation, wastewater has an important role to play in water resources management. By releasing freshwater sources for potable water supply and other priority uses, wastewater reuse makes a contribution to water conservation and takes on an economic dimension. Moreover, wastewater reuse schemes, if properly planned and managed, can have positive environmental impact, besides providing increased agricultural yields. Environmental improvement and benefits accrue as a result of several, including:

- Prevention of surface water pollution, which would occur if the wastewaters were not used but discharged into rivers or lakes. Major environmental pollution such as dissolved oxygen depletion, eutrophication, foaming, and fish kills can be avoided. Planned reuse of wastewater for irrigation prevents such problems and reduces the resulting damage that if quantified, can partly offset the costs of the reuse scheme.
- Conservation of fresh water resources, or their more rational usage, especially in arid and semi-arid areas: freshwater for urban demand, wastewater for agricultural use.
- The use of wastewater for irrigation may lessen the degree of groundwater exploitation, avoiding seawater intrusion in coastal areas.
- The plant nutrients which may eventually pollute environment if raw wastewater or even treated effluent (especially organic matter, nitrogen, phosphorus and potassium) are discharged directly to the environment may serve as plant nutrients when applied as irrigation water. This reduces requirements for artificial fertilizers, with a concomitant reduction in energy expenditure and industrial pollution elsewhere.
- The organic matter added through wastewater irrigation serves as a soil conditioner over time, increasing its water holing capacity. In addition through the

soil humus build-up, preventing of land erosion and soil conservation could be achieved.
- Desertification and desert reclamation, through the irrigation and fertilization of tree belts.
- Improved urban amenity, through irrigation and fertilization of green spaces for recreation (parks, sports facilities) and visual appeal (flowers, shrubs, and trees adjacent to urban roads and highways).

Some degree of treatment must normally be provided to raw municipal wastewater before it can be used for agriculture. The quality of treated effluent used in agriculture has a great influence on the operation and performance of the wastewater-soil-plant system.

The most appropriate wastewater treatment to be applied before effluent use in agriculture is that which will produce an effluent meeting the recommended microbiological and chemical quality guidelines, both at low cost and with minimal operational and maintenance requirement. Adopting as low a level of treatment as possible is especially desirable in the Mediterranean region, not only from the point of view of cost but also in acknowledgement of the difficulty of operating complex systems reliably.

In the coming years, for the Mediterranean region, research should support the innovative approach of extracting reusable water for then using the value elements. Treated wastewater should be considered as “two in one” resource: water and value elements.

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Treatment and Reuse of Sludge

Maria Fuerhacker and Tadele Measho Haile

Abstract Almost all over the world, the production of sewage sludge rises due to increased population, industrialization and urbanization. Treatment and disposal of sewage sludge is an expensive and environmentally challenging task, problems arising mainly from lack of social acceptability, high treatment costs, human and environmental health risks associated with treatment and lack of sustainable disposal options. Currently the most widely available and recommended option is land application of sewage sludge. It is also a growing problem worldwide since there is a special concern about organic contaminants and the discussion about potential standards.

The aim of this paper is to assess the challenges to planners and policy makers with regard to sludge management. Constantly increasing environmental concerns require to identify the occurrence, type and concentration of pollutant, assess treatment efficiencies of different treatment methods as provided in literature and to evaluate the existing sludge disposal options and propose a sustainable and safe option.

Different groups and levels of inorganic (heavy metals) and organic substances and the problems of pathogens in sludge are pointed out. The mere concentration of a potential health hazards does not give any information on the connected risk. The outcomes of different risk assessments for metals and organic contaminants are listed. As it will never be possible with single substance analyses to have sufficient information an alternative approach for effect monitoring is described.

Recycling and use of wastes are the preferred options for sustainable development, rather than incineration or land filling, but with sewage sludge this is not straight forward because of perceptions over inorganic and organic contaminants, pathogens and its fecal origin, particularly by the food retailers. For the assurance of

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public and environmental health, a quality system and standards for the treatment and the produce are recommended, which need to be accepted by all stakeholders as farmers, food retailers and public requirements.

The paper demonstrates that treated sewage sludge, which fulfils the quality requirements for heavy metals, organic compounds and pathogens, can be beneficially reused providing a land application of restricted amounts as a long-term sustainable waste management solution for sludge from municipal waste water treatment plants. In the future sludge management needs to be based on sustainability and beneficial reuse, and the treatment technology has to be effective and affordable. The treatment options have to be adapted to local situations to fit the socio-cultural framework, available technology and affordability as well as local climatic conditions. Therefore, it is recommended to include environmental, social, economic and technical analysis in the search for the most sustainable alternative for sludge disposal.

Keywords Heavy metals, Land application, Organic contaminants, Pathogens, Regulations, Risk assessment, Sewage sludge

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1 Introduction

With the public desire to protect surface waters from sewage contamination, waste water treatment plants are designed to clean the raw wastewater and separate it from the solids and other contaminants, and return the treated waste fraction to the surface waters or reuse it for several applications. The remaining solid fraction is called, depending on the country, either sewage sludge or biosolids. The main objective of the design of wastewater treatment plants is the prevention of oxygen depletion and eutrophication in surface waters, which means that they are not designed to treat the sludge effectively; they are primarily designed to clean the water fraction. In developing as well as in developed countries the volume of wastewater produced increases simultaneously with increasing urbanization and industrialization. In case the water is not or not sufficiently treated the pollution of surface water increases, otherwise more sewage sludge is produced. In the EU, the implementation of the Urban Waste Water Treatment Directives 91/271/EEC leads to a 50% increase in sludge production, from 5.5 million tons of dry matter in 1992 to 9 millions tons of dry matter by the end of 2005. The composition and properties of sewage sludge depend, to a large extent, upon the type and original pollution load of the wastewater, the treatment technology, the type of sludge treatment processes applied and on seasonal factors like the wastewater temperature.

Besides domestic sewage industrial effluents, storm-water runoff from roads are also frequently discharged into sewers.

In addition to organic waste material and traces of pollutants which might be phytotoxic or toxic to humans and/or animals, sewage sludge will contain microbial contaminants (pathogenic bacteria, viruses and protozoa along with other parasitic helminths).

Due to the increasingly stringent controls on sludge disposal the safe handling of sewage sludge in an economically and environmentally acceptable way presents an important challenge to wastewater authorities. Apart from some components of concern, sewage sludge contains high concentrations of valuable substances like nitrogen, phosphorus and organic matter which should be reused, e.g., as agricultural soil amendment or as fertilizers. Due to the beneficiary properties and the general policy for waste management it is encouraged to recover values from waste products, e.g., in agriculture and to reduce the disposal of biodegradable wastes in landfill. Phosphorous is a diminishing element and needs to be preserved. This aspect is well known and out of discussion, nevertheless, there is concern of different stakeholders about potential contaminants in sludge and their negative effects.

The aim of this paper is to assess the challenges to planners and policy makers with regard to sludge management while addressing the constantly increasing environmental concerns. The study highlights that sludge management needs to be based on maximizing sustainability and beneficial reuse in the future, and the treatment technology has to be effective and affordable. To achieve this target different options of treatment and disposal pathways are compared in terms of their removal efficiency and sustainability.

2 Definitions

In the EC scientific and technical report [1] sewage sludge is defined as follows: "Sludge is a by-product of the water clean up process." Sewage sludge would then be sludge from urban waste water treatment plants (UWWTPs), septic tank sludge would be sludge from septic tanks which contain human excreta and domestic waste water from single or multiple human dwellings, and industrial sludge would be sludge from the treatment of industrial waste water of the sectors listed in Annex VIII (third Draft). This paper deals with sludge from UWWTP only.

3 Contaminants

Pollutants in sewage sludge can generally be grouped into three main categories: (1) inorganic contaminants (e.g., metals and trace elements); (2) organic contaminants (OCs) (e.g., polychlorinated biphenyls (PCBs), polychlorinated dibenzodioxins/furans (PCDD/Fs), pharmaceuticals and personal care products (PPCPs), polyaromatic hydrocarbons (PAHs) and surfactants); and (3) pathogens (e.g., bacteria, viruses and parasites). Bastian et al. [2] reported the occurrence of radioactive contaminants in sewage sludge and ash from natural and human-made sources (such as feces and urine from people undergoing radiation therapy) [2].

3.1 Heavy Metals

Sewage sludges contain heavy metals from domestic, commercial and industrial origin and surface runoff, especially those from heavily urbanized and industrialized areas contain relatively high levels of potentially toxic trace metals which can accumulate after continual application to land [3], and may increase the risk of these components entering the food chain [4] or cause phytotoxic effects that can pose a threat to the human and environment health if not managed in a safe way [3, 5].

Among the heavy metals of human and environmental health concern, special attention has been given to the trace metal cations: lead (Pb), zinc (Zn), cadmium (Cd), chromium (Cr), copper (Cu), mercury (Hg) and nickel (Ni) [1, 5–8]. Despite their inclusion in the list of priority sewage sludge contaminants the anionic trace metals: Arsenic (As), Molybdenum (Mo), Selenium (Se) and Chromium (Cr) have received less attention. Nevertheless, important differences in the soil chemical reactions of the two groups are recognized, especially the difference in elemental solubility and soil adsorption with pH [9]. To assess the fate and transport, but also the mobility, bioavailability and eco-toxicity of heavy metals in sludge-amended soils information on the nature (form, solubility, charge) and factors including pH, cation exchange capacity (CEC), organic matter content, soil structure, and soil texture is fundamental [5, 9, 10].

Heavy metal content of sewage sludge as reported in most research works is variable and hardly comparable (Table 1).

The concentration of heavy metals in sewage sludge is highly dependent on its source (domestic wastewater and industrial wastewater), sludge pre/treatment processes applied, but the observed differences can also be attributed to the analytical

Table 1 Heavy metals content of various sludges (mg kg^{-1} DM)

Country	Cd	Cr	Cu	Hg	Ni	Pb	Zn	References
Canada	2.3–10	66–2,021	180–2,300		37–179	26–465	354–640	[11, 12]
China	5.9–13	46–78	131–395	17–24	49.3–95.5	58–109	783.4–3,096	[13]
Egypt	0.9–312	89–993	83–2,640	0.1–16	5–645	50–1,724	112–6,298	[14]
Germany	0.8–16.6	16–66	168–228	0.65–2.5	24–39	34–49	674–827	[15]
India	41–54	102–8,110	280–543		192–293	91–129	870–1,510	[8, 10]
Spain	1.0–3.0	122–244	275–331	1.5–1.7	32–64	71–105	500–880	[6]
Spain	1.0–2.0	163–318	200–575	1.0–2.0	55–152	70–167	540–2,100	[16]
Thailand	4.8	264	3,043		298	175.2	1,908	[17]
Turkey	1.3	321	388		128	29.2	541	[79]
UK	3.5	159.5	562		58.5	221.5	778	[80]
USA	25	178	616		71	170	1,285	[18]

techniques used. Based on sampling and analysis as well as previous studies, Ghazy et al. [14] presented a brief overview of the existing sludge characteristics and management practice in Egypt. The characteristics of sewage sludge with respect to heavy metal (Zn, Cu, Pb, Cd, Cr, As, Hg and Ni) content were assessed based on sampling and analysis as well as previous studies. The results demonstrated that sewage sludges vary widely in the concentration of heavy metals. Generally the sewage sludge produced from the Egyptian WWTPs did not have high heavy metal contamination except in few cases, which can be attributed to irregular contributions from industrial areas, suggesting that wastewaters from a big city are a lot more laden.

Hoffmann et al. [15] assessed the influence of analytical methods on heavy metal content of different sludge types using standardized and adjusted methods (elemental analysis, atomic absorption spectroscopy, X-ray fluorescence spectroscopy (X-RFA) and ion chromatography (IC)) and found that in some countries this aspect needs to be considered.

Three decades ago the concentration of heavy metals in sewage sludge was found to be nearly 0.5–2% on dry weight basis, which may go up to as high as 6% in some cases [19]. In Europe and US the concentrations of heavy metals in municipal sewage sludge steadily declined not only due to pretreatment standards and strict regulations for the sludge application but also due to voluntary agreements and improved industrial practices.

The form of organic matter (soluble or insoluble) affects the bioavailability of heavy metals. Insoluble organic matter inhibits the uptake of metals, which are tightly bound to organic matter and reduce the bioavailability. Soluble organic matters, however, increase the availability by forming soluble metal organic complexes [20]. Furthermore, surface charge on organic matter and oxyhydroxides increases with pH, thereby increasing their sorptive capacity for metals (thus decreasing metal bioavailability), conversely positive surface charges increase as the pH drops, which increases the sorption of anion trace metals (e.g., As, Mo or Se) under low pH conditions and decreasing sorption of cation ionic metals. The mobilization, bioavailability and eco-toxicity of metals depend on the species present, pH, temperature, oxidation–reduction potential, organic matter decomposition, leaching, ion exchange processes and microbial activity [5]. The higher heavy metal content of sludge-amended soil in conjunction with pH reduction, in the long-term, could modify metals behavior in the environment, with unpredictable future consequences on soil ecology. Metals in the soil can be mobilized by natural leaching processes or decomposing of the organic matter, and through plant uptake enters the food chain [4]. To investigate the bioavailability of Cu, Ni, Pb and Zn in soil amended with sewage sludge (80, 130 and 160 tons ha^{-1}), Morera et al. [21] conducted a greenhouse experiment using sunflower plants (*Helianthus annuus* L.) and found that sludge amendment increased the average dry weight of sunflower plants (*H. annuus* L.), and the concentration of metals in the plants increased with the sewage sludge dose. More interesting was the effect of the soil type on the metal concentration in plants which turned out to be more important than the dose, whereby bioavailability of Zn from sewage sludge was favored in the acid soil, whereas Cu bioavailability was greater in the alkaline soils.

3.2 Organic Contaminants

Depending on the properties (accumulation, degradation or volatility), we will be able to find most of the chemicals we use for technical processes or in our daily life in sewage sludge as far as we look for them and have sensitive analytical tools; many of them we find in the μg kg^{-1} DM range. Nevertheless, the mere presence does not give an idea about the risk. The presence of organic contaminants in sludge has earned much greater attention in recent years. Most research works focused on organic chemicals that are persistent in the environment and/or toxic to humans and animals. Harrison et al. [22] conducted an extensive survey of reviewed literature and official governmental reports and they reported that the concentration of OCs in soil resulting from land application of sludge depends on: initial concentration in the sludge and soil, the rate of application, management practices and losses. In their report they concluded that although there is no requirement to test sewage sludges for the presence of OCs in the US, to fill gaps in knowledge there is a need for a survey of OCs in sewage sludges and for further assessment of the risks they pose. Drescher-Kaden et al. [23] conducted a literature review of 900 publications regarding OCs in German sewage sludges and reported that 332 organic substances, with the potential to pose a health or environmental hazard, had been identified and 42 of them were regularly detected in the sludge. Different studies investigated potential organic contaminants in sludge; due to improved analytical techniques detection limits in the sub-nanogram-range are possible. The range of OCs known to exist in sludge is extensive and diverse, the respective lists include: detergents (e.g., linear alkylsulfonates, nonylphenol (NP) ethoxylates (EO), dialkyldimethylammonium ions), products of incomplete combustion (polycyclic aromatic hydrocarbons (PAHs), and polychlorinated dibenzodioxins and furans (PCDD/Fs)), PCBs, solvents (e.g., chlorinated hydrocarbons, chlorinated paraffins), flame retardants (e.g., polybrominated diphenyl ethers, fluorinated compounds), plasticizers (e.g., phthalates), agricultural chemicals (e.g., pesticides), pharmaceuticals (e.g., antibiotics, hormones) and personal care products (e.g., triclosan, musk fragrances) [24, 25].

The specific fate and transport of some groups of organic pollutants as investigated by researchers is given below.

3.2.1 Detergents: Linear Alkylbenzene Sulfonates and Nonylphenol/Ethoxylates

Linear alkylbenzene sulfonates (LASs) are the most widely used anionic surfactants in cleaners and detergents for domestic and industrial applications. The annual usage rate is approximately 430,000 and 1–2.5 million tons per annum in Western Europe and worldwide, respectively [26]. They concentrate in sludge but undergo rapid biodegradation under aerobic conditions and hence are to a large extent removed during wastewater treatment (typical range 95–99.9% in activated sludge systems) [27]. Due to these chemical properties, LAS levels are much higher in anaerobic-digested sludge (~50–30,000 mg kg^{-1} DM) than fresh aerobic sludges (typically <1,000 mg kg^{-1} DM) and aerobic-digested sludge (100–500 mg kg^{-1} DM) [6, 28–30]. The LAS content of aerobic-digested sludge is usually lower than the proposed EC Working Document on Sludge (2,600 mg kg^{-1} DM). LAS loading through land application of sludge disappears rapidly from the soil as a result of aerobic biodegradation with primary and ultimate half-lives of up to 7 and 30 days, respectively [27]. Petersen et al. [30] conducted plot experiment with banded sludge to examine the fate and effect of sludge-amended soil, at an application rate of 3–4 Mg DM ha^{-1}. They found that the degradation of NP and LAS was fast with almost identical pattern of decline. Around 70% of the initial amount was degraded within the first 6 weeks, and <5% of NP and LAS remained after 6 months.

In some countries (e.g., Germany, Austria, Swiss, Denmark) there is a voluntary ban of the industry for the use of NPEO in household detergents. In countries without voluntary ban like Spain, sewage sludge samples collected from eight different sludge treatments showed high concentration levels of NP (mean value 88.0 mg kg^{-1} DM) than NP1EO (mean value 33.8 mg kg^{-1} DM) and NP2EO (mean value 14.0 mg kg^{-1} DM). In wastewater treatment plants NP and short-chained ethoxylates NP1EO and NP2EO are formed as degradation products from non-ionic alkylphenole polyethoxylate surfactants used in large amounts in industry and agriculture [24, 26, 31]. Highest concentrations were found in samples of compost, anaerobically-digested sludge, lagoon sludge and aerobically-digested sludge samples, which contained NPE concentrations in the ranges 44–962 mg kg^{-1} DM, 8–669 mg kg^{-1} DM, 27–319 mg kg^{-1} DM and 61–282 mg kg^{-1} DM, respectively. More than 75% of sludge samples analyzed contained NPE concentrations higher than the limit of 50 mg kg^{-1} DM fixed in the EU Directive draft [32]. The half-life of NP in soil is typically 20 days [28].

3.2.2 DEHP

DEHP is a major bulk chemical found in sludge, belongs to the esters of phthalates, which are all esters of the phthalic acid. DEHP may be used as a plasticizer, with application in the construction and packaging industries (i.e., in the production of PVC) as well as in the production of components of medical devices, accounting for over half of the total use of phthalates. It is also the most well studied of this group of compounds due to its persistence to biodegradation in anaerobic-digested sludge. Phthalate esters are, however, rapidly destroyed under aerobic conditions, and biological wastewater treatment (e.g., activated sludge process) can usually achieve more than 90% removal in 24 h [24]. DEHP shows rapid degradation in soils with half-life <50 days [28]. Fifty percentage of the DEHP are degraded within a time span from 1 week to 3 months after application of sludges on agricultural soils [81].

Although DEHP is expected to sorb firmly to sludge particles, the concentration in sludge is sufficiently high to result in measurable concentrations in water extracts [30]. The concentrations of DEHP in sludge ranged between 0.34 and 1,020 mg kg^{-1} DM [24] and its degradation is strongly reduced under anaerobic conditions [30]. The mobility and bioavailability of DEHP is very low due to its stronger adsorption ($\log K_{ow} = 7.6$) to soil [30]. Thus, DEHP has received much less attention than LAS and NP in terms of the toxicological and eco-toxicological implications of recycling sewage sludge to agricultural land. In many aspects, if controls were imposed on this compound in sludge or to reduce its emission to the environment (for example, DEHP is subject to review for identification as a possible priority hazardous substance under the WFD) [24].

3.2.3 Polybrominated Diphenyl Ethers

Polybrominated diphenyl ethers (PBDEs) are a group of compounds used in large quantities for several applications due to their fire-retarding properties, including electrical appliances such as television and computers, building materials, plastic material and synthetic fibers and textiles. These compounds have now accumulated within many environmental compartments and living organisms resulting in the exponential concentrations in humans over the last three decades. The molecular structure and properties of PBDEs are similar to that of the environmental toxic pollutants such as PCDD/Fs, PCBs, and their resistance to degradation processes gives rise to concern that they may lead to similar environmental problem and evidence, suggesting that low-level exposures may produce detrimental health effects in humans and animals [33]. A survey of Australian, Spanish, German and US sludges indicate that the mean concentrations for PBDE (23 congeners) are up to 1,540 μg kg^{-1} DM, with little difference between urban and rural origin [34, 35, 82, 83]. In all the cases, the BED-209 was predominant as compared to the other congeners. An experimental study by Mueller et al. [36] indicated that interspecific plant interactions may enhance PBDE bioavailability in soil. Thus, although abiotic sorption may limit the potential for human exposure to PBDEs in soil, plants may increase the exposure risk by taking up and translocating PBDEs into the above-ground tissues and by enhancing bioavailability in soil. This bioavailability of PBDEs in planted soils has implications on possible microbial degradation of PBDEs, trophic interactions; consumption of plant tissue could be an important route of oral exposure [36].

3.2.4 AOX

AOX represents a wide range of substances that are defined by the binding of a halogen-containing chemical to activated carbon, and include chemicals of differing structures and toxicological profiles. The concentration of AOX in soil from several countries (Sweden, The Netherlands, etc.) has been reported at 30–600 mg kg^{-1} DM.

A comparison of the biodegradation of AOX in thermophilic and mesophilic anaerobic digestion of activated sludge at different hydraulic retention times showed an enhanced AOX biodegradation under thermophilic conditions. The total AOX removal efficiency was in the range of 40.4–50.3% for thermophilic conditions and 30.2–43.2% for mesophilic conditions. The AOX content in the treated sludge of both thermophilic and mesophilic digesters did not exceed the limit proposed in the third Draft [37] Working Document on Sludge [38].

3.2.5 Pharmaceuticals and Personal Care Products

Many of the PPCP are strong hydrophilic and might be present if liquid sludge is used. Removal of PPCPs during municipal wastewater treatment is rarely complete, thereby creating a pathway for entry of these compounds into terrestrial environments via land application of sludge [39, 40]. Anaerobic digestion of sewage sludge from Spain showed a wide range of removal efficiencies, pharmaceutical and PPCPs, during wastewater treatment which were grouped as: very high removal (>85%) of naproxen, sulfamethoxazole, roxithromycin and oestrogens; high removal (>60%) of galaxolide, tonalide and diclofenac; medium removal (40–60%) of diazepam and ibuprofen; low elimination (~20%) of iopromide and no removal of carbamazepine [16]. Triclosan (TCS) and triclocarban (TCC) are antimicrobial agents widely used in many PPCP such as soaps, detergents, toothpastes, disinfectants, cosmetics and pharmaceuticals and will end up in the wastewater. Triclosan concentration in PPCPs is typically in the range of 0.1–0.3 (W/W) [87]. In Europe, consumption of triclosan is about 350 tons per annum [84]. In the United States National Sewage Sludge Survey, the mean concentrations of 72 pharmaceuticals and PPCP determined in 110 sewage sludge samples collected from 94 WWTPs indicate that 38 (54%) of the 72 analytes were detected in at least one composite sample at concentrations ranging from 0.002 to 48 mg kg^{-1} DM. Among the detected compounds the two most abundant contaminants were the disinfectants, TCC (48% of total detected PPCP mass) and TCS (17%) with mean concentrations of 36 $\pm$ 8 and 12.6 $\pm$ 3.8 mg kg^{-1} DM, respectively [41]; also Heidler et al. [42] reported that TCC concentrations ranging from 5.97 to 51 mg kg^{-1} DM have been detected in every composite sample assayed. Pharmaceuticals and PPCPs have been detected also in agricultural soils subjected to land application of digested municipal sludge [43]. There are very few studies in the literature about the extent to which PPCP and pharmaceutical residues are accumulated in sewage sludge and the fate of these compounds when the sludge is land applied, thus more accurate data are required to conduct reliable exposure and hazard assessments [44].

3.3 Pathogens

Sewage sludges contain a broad range of pathogenic organisms, including viruses, bacteria, parasitic protozoa and helminths, which might transmit to soil, food or groundwater. Land application of sewage sludge can lead to the transport of pathogens through bioaerosols downwind of sludge storage or spreading sites, through contamination of ground water, drinking water wells, ponds and surface waters, or through food contamination from eating food grown in sludge spread land. The number of pathogens present in wastewater and sludge varies as a function of numerous factors including geographic location, socio-economic status, sanitary conditions, season and the incidence of enteric infections within a community and the treatment levels of the sludge. The occurrence of human pathogens is of utmost concern, especially those pathogens that infect through the fecal-oral route, although respiratory and blood-borne organisms may occur although the prevalence is generally low. Using sewage sludge as fertilizer might short-circuit the fecal-oral transmission route and raise the possibility of spreading epidemic diseases and threat human and veterinary health unless the pathogens in the wastes are effectively inactivated or eliminated. The protozoa, *Cryptosporidium*, *Guardia* and *Toxoplasma*, are the most significant causes for food- and water-borne infections. Among the pathogens of concern, helminth eggs are the most resistant due to the complex layers that protect them [45]. Cattle become infected by ingesting tapeworm eggs present in human feces and sludge. Infections with the helminths, *Taenia saginata* in cattle or *Taenia solium* in pigs, are one of the primary human zoonotic meat- or food-borne trematodiases. Their life cycles depend on the link between humans and cattle (*T. saginata*) or pigs (*T. saginata asiatica* and *T. solium*). Bovine cysticercosis is caused by the larval stage of the beef tapeworm *T. saginata*, where humans are the final hosts of the parasite. Humans get infected by eating raw or uncooked meat infected with cysts of these parasites which are found in industrialized countries as well as in developing countries with high prevalence levels in Sub-Saharan Africa, Latin America, South and South-East Asia, and it has been estimated that millions of persons worldwide are infected [46]. In Eastern Africa it causes an important economic loss due to condemnation of meat [47]. Fan and Chung [48] estimated that the annual economic loss due to taeniasis (all species including *Taenia asiatica*) in the mountainous regions of Taiwan, Cheju island of Korea and Samosir island of Indonesia amounted to US$ 18 million, US$ 13 million and US$ 2.4 million, respectively. However, in reality, risks of serious illness and mortality are far greater from enteric viruses than from helminths [49].

4 Risk Assessments

Although sewage sludge recycling has potential resource value as a fertilizer, there is great environmental and health risk concern with regard to concentrations of potentially toxic chemicals (heavy metals and OCs) or pathogens which may accumulate in agricultural soil in the long-term.

Risk Assessment (RA) consists of four steps: (1) hazard identification, describing acute and chronic human health effects associated with any particular hazard, including pathogens or toxic chemicals; (2) hazard characterization which corresponds to dose–response assessment, to characterize the relationship between various doses administered and the incidence of the health effect; (3) exposure assessment to determine the size and nature of the population exposed and the route, amount and duration of the exposure and (4) risk characterization to integrate the information from the exposure, dose–response and hazard identification steps in order to estimate the magnitude of the public health problem and to evaluate variability and uncertainty [50].

For a risk assessment, exposure and effect data need to be compared. In terms of health risk the World Health Organization published the third edition of its "Guidelines for the Safe Use of Wastewater, Excreta and Greywater in Agriculture" in September 2006 [50]. This document shall form the basis for the development of local approaches to control health risks and to attain local health-based targets. Health targets can be achieved by using a combination of management approaches or intervention methods such as wastewater and sludge treatment and washing the produce. To verify if it is feasible to attain such goals using different combinations of intervention methods, a quantitative microbiological risk assessment (QMRA) may be used.

4.1 Heavy Metal

In the risk assessment under the 40 CFR 503 rules, the EPA evaluated 14 possible pathways of exposure for land application of sewage sludge and the potential risk to health and the environment they may pose and came up with standards for concentrations in sewage sludge, annual pollutant loading rates and cumulative metal pollutant loading rates [51, 52]. In the EU (Directive 86/278/EEC), concentration limits are defined for Cd, Cu, Ni, Pb, Zn and Hg in both sewage sludge and soil. Limit values for heavy metals in sludge, which are defined in national regulations along with Directive 86/278/EEC, EPA rule 503 and some countries regulations are presented in Table 2. Sewage sludge exceeding the standards for heavy metal elements could on a long-term adversely affect the quality of soil.

The EU, Directives 91/271/EEC concerning urban waste water treatment and 86/278/EEC on the use of sludge in agriculture, has the strongest impact on sludge production, disposal and recycling. Member states were enforced to established national regulations on the basis of Directive 86/278/EEC. The limit values for concentrations of heavy metals in sludge as compared to the EU Directive 86/278/ECC showed that apart from zinc, most of the Member States have set their limit values below the maximums allowed by the Directive. In the case of zinc, a majority of Member States have set their limits close to those allowed by the Directive.

The existing national regulations as compared to the EU regulation with regard to heavy metals and pathogens are presented in Table 3.

Owing to their low concentration levels and very low exposure, radioactive materials are likely to be of no concern. As a result, presently there are specific regulations that limit the level of radioactive materials present in sewage sludge.

Table 2 Limits of heavy metal concentrations in sludge [mg kg^{-1} DM] modified from Directive 86/278/EEC [13, 14, 17, 52, 53]

Heavy metal	Cd	Cr	Cu	Hg	Ni	Pb	Zn	As	Mo	Co
Directive 86/278/EEC	20–40	–	1,000–1,750	16–25	300–400	750–1,200	2,500–4,000			
Lower Austria	2	50	300	2	25	100	1,500			2
Upper Austria	10	500	500	10	100	400	2,000			
Burgenland	10	500	500	10	100	500	2,000			
Vorarlberg	4	300	500	4	100	150	1,800			
Steiermark	10	500	500	10	100	500	2,000	20	20	100
Carinthia	0.7–2.5	70–100	70–300	0.4–2.5	25–150	45–150	200–1,800			
Belgium(Flanders)	6	250	375[a]	5	100	300	900[a]	150		
Belgium (Wallon)	10	500	600	10	100	500	2,000			
Denmark										
Dry matter basis	0.8	100	1,000	0,8	30	120[b]	4,000	25[c]		
Total P basis	100			200	250	1,000[b]				
Finland	3	300	600	2	100	150	1,500			
	1.5[e]			1[d]		100[d]				
France	20[e]	1,000	1,000	10	200	800	3,000			
Germany	10	900	800	8	200	900	2,500			
Greece	20–40	500	1,000–1,750	16–25	300–400	750–1,200	2,500–4,000			
Irland	20	–	100	16	300	750	2,500			
Italy	20	–	1,000	10	300	750	2,500			
Luxembourg	20–40	1,000–1,750	1,000–1,750	16–25	300–400	750–1,200	2,500–4,000			
Netherlands	1.25	75	75	0.75	30	100	300			
Portugal	20	1,000	1,000	16	300	750	2,500			
Spain										
Soil pH < 7	20	1,000	1,000	16	300	750	2,500			
Soil pH > 7	40	1,750	1,750	25	400	1,200	4,000			
Sweden	2	100	600	2.5	50	100	800			
UK		PTE regulated through limits in soil								

(*continued*)

Table 2 (continued)

Heavy metal	Cd	Cr	Cu	Hg	Ni	Pb	Zn	As	Mo	Co
Accession countries										
Estonia	15	1,200	800	16	400	900	2,900			
Lativia	20	2,000	1,000	16	300	750	2,500			
Poland	10	500	800	5	100	500	2,500			
	None EU countries									
EPA 503	39		1,500	17	420	300	2,800	41		
China										
PH $<$ 6.5	5	600	800	5	100	300	2,000	75		
pH $>$ 6.5	20	1,000	1,500	15	200	1,000	3,000	75		
Egypt	39	1,200	1,500	17	420	300	2,800	41		
Thailand	20	1,000	900		400	1,000	3,000			

[a] These values are reduced to 125 (Cu) and 300 (Zn) from 31/12/2007

[b] For private gardening, lead value is reduced to 60 mg kg^{-1} DM or 5,000 mg kg^{-1} P

[c] For private gardening

[d] Target limit values for 1998

[e] 15 mg kg^{-1} ds from January 1, 2001 and 10 mg kg^{-1} DM from January 1, 2004

Table 3 National requirements as compared to EU requirements [54]

Much more stringent	Denmark, Finland, Sweden, Netherlands
More stringent	Austria, Belgium, France, Germany (Poland)
Similar	Greece, Irland, Italy, Luxembourg, Portugal, Spain, UK. (Estonia, Lativia)

The use of sludge was also restricted by setting maximum quantities for the amounts of sludge used per annum. In addition, the pH value and the soil consistency is considered in some countries. Chromium was on the list but was not given a limit. In addition, some Member States have set limits for arsenic, fluoride, molybdenum, cobalt and selenium. Although it will never be possible to achieve an input–output balance, to minimize the accumulation of heavy metals reduction in limit concentration as far as possible is demanded.

A recent risk assessment of sludge in soil conducted by INERIS for European Federation for Agricultural Recycling (EFAR) considered the presence of the metals cadmium, chromium III, copper, mercury, nickel, lead and zinc (together with the organic compounds, mentioned in Drafts related to revision of the Sludge Directive in 2003) [55]. They evaluated the potential hazard of each substance to derive a toxicological reference value (TRF), which they compared with an exposure value to give a hazard quotient (Exposure ÷ TRF), a value over 1 being considered concern for human health. The exposure value considered consumers, neighbors and farmers as receptors, and ingestion via soil, water, animals, vegetables and fish for a 70-year lifespan. The results confirmed that the major exposure pathway is the ingestion of plants and animals. The major substances were the heavy metals, zinc, lead, cadmium, copper and nickel. The study concluded that the contribution of sludge spreading to land to the global risk is low compared to the ingestion of food produced on non-spread lands. Nevertheless, the report suggested a reduction in the permissible Pb concentration in sludge for recycling from a maximum of 750 mg kg^{-1} DM (in 86/278/EEC) to 500 mg kg^{-1} DM. This would achieve an acceptable level of risk with 70 years of exposure based on very conservative assumptions.

Smith [56] points out that there remains further incentive to reduce the concentrations of problematic contaminants, PTEs in particular, in sludge. He suggests that this should continue to be a priority and pursued proactively by environmental regulators and the water industry as improving the chemical quality of sludge as far as practicable is important to ensure the long-term sustainability of recycling sewage sludge in agriculture.

Monitoring and research needs to continue to assess the significance of new developments (including PTEs of new interest, e.g., tungsten) as they arise.

4.2 Organic Contaminants

For OCs, there is no consistent approach in setting limit values in sludge between different countries. In the US the USEPA under 40 CFR Parts 257 and 503 (1993) conducted a risk assessment for a big variety of organic compounds but did not provide any limit values or requirements for organic compounds in sewage sludge for one or more of the following reasons: (1) the pollutant was detected in less than 5% of the sludge, (2) the concentration of the pollutant was low enough that it would not exceed the risk-based loading rates or (3) the pollutant was banned in the US and was no longer manufactured. A review of scientific literatures indicated that recycling of sewage sludge to agricultural land is not constrained by the presence of OCs, as no unacceptable risk for soil quality, human health or the environment could be observed in different risk assessments at the usual concentrations. As a result, some countries, such as the UK and Canada, have argued that there is no technical justification for setting limits on OCs in sludge [24]. A similar approach is adopted in the 86/278 EU Directive, but this justification does not adequately address the potential for adverse health effects from organic chemicals. The third Draft of the "Working Documents on Sludge" [37] proposes limit values for concentrations of the selected OCs or, respectively, groups of compounds if sludge is to be used in agriculture (Table 4). European Commission has had different opinions about which compounds to regulate and what limit values to adopt in proposals to revise Directive 86/278/EEC [37, 57], reflecting the complexity of the decision-making process and the differences of opinion within a single regulatory body.

Table 4 Limit values of organic contaminants (PCDD/Fs, PCBs, AOX, LAS, DEHP, NP/NPEs and PAHs) in sewage sludge (mg kg^{-1} dry solids (DS) except PCDD/F: ng toxic equivalents (TEQ) kg^{-1} DM) [24, 37, 57]

	PCDD/Fs	PCBs	AOX	LAS	DEHP	NPE	PAH
EC (2000a)*	100	0.8[e]	500	2,600	100	50	6[h]
EC (2003)*	100	0.8[e]		5,000		450	6[h]
Austria	100[a,b,c]	(0.2[a,b,c])[f]	500[a,b,d]				
	50[d]	(1[d])[h]					(6[d])[h]
Denmark							
from 1/07/2000				1,300	50	30	3[h]
from 1/07/2002				1,300	50	10	3[h]
France		0.8[e]					9.5[i]
		0.5[g]					
Germany	100	0.2[f]	500				
Sweden		0.4[e]				100	3[j]

*Proposed but withdrawn and basis subject to review
[a]Lower Austria
[b]Upper Austria
[c]Vorarlberg
[d]Carinthia
[e]Sum of 7 principal PCBs (PCB 28, 52, 101, 118, 138, 153, 180)
[f]Each of the six congeners (PCB 28, 52, 101, 138, 153, 180)
[g]For pasture
[h]Sum of acenapthene, phenanthrene, fluorene, fluoranthene, pyrene, benzo(b + j + k)fluoranthene, benzo(a)pyrene, benzo(ghi)perylene and indeno(1, 2, 3-c,d)pyrene
[i]Sum of three congeners: fluoranthene, benzo[*b*]fluoranthene and benzo[*a*]pyrene
[j]Sum of six compounds

Table 5 Proposed standards for OC in mg kg^{-1} DM, unless specified [25]

OC group	Compound	Limit value
Chlorphenole	Triclosan	0.5–3
Musk fragrances	Galaxolid	≤5
	Tonalid	≤2
Organotin compounds	Monobutylin	0.1–0.2
	Dibutylin	0.01–0.015
	Tributylin	0.05–0.03
Polybrominated diphenyl ethers	Pentabromdiphenylether	≤0.04
	Decabromdiphenylether	≤0.3
Polyaromatic hydrocarbons	Benzo(a)pyren	0.04–0.3
	Chrysen	≤0.4
Polychlorinated biphenyls	PCB6	≤0.05
Polychlorinated dibenzodioxins/furans	PCDD/Fs	2–10 ng kg^{-1} TR
Phthalate	DEHP	20–50
	LAS	1,100–1,200
Tenside	Nonylphenol	5.0–10

After an intensive monitoring and risk assessment in Nordrhein-Westfalia (Germany), Barkowski et al. [25] consider the compounds listed in Table 5 as being relevant and proposed to develop standards accordingly.

The conclusions and recommendations of the study of Barkowski et al. [25] were seriously questioned by a group of experts of DWA (German Water Association) [58], as a study of Dreher et al. [59] indicated that the difference between fields which have been amended with sludge (up to 31.5 tons DM ha^{-1} $year^{-1}$) for 11 years compared to fields without sludge application gave for six groups of selected compounds no detection, for three groups no difference and only for three groups (tributyltin, musk fragrances, PCDD/F) slightly higher concentrations than the non-amended fields. The experts recommend that the real behavior should be clarified before quality standards for OC are set. This result was also obtained from Bursch et al. [60].

According to Smith [61], five characteristics of sludge organic contaminants should be considered in order to assess the risk posed when sewage sludge is applied to farmland soil. These characteristics are: degradation in the field, the leaching potential, plant uptake and transfer along the food chain and ultimately to man and finally the initial concentration in soil.

Chaney et al. [62] conducted a Pathways Approach to assess the risk of organic compounds in sewage sludge used on agricultural soil. In their study they found two pathways: (1) ingestion of biosolids by children and (2) the greatest risk from persistent lipophilic OCs arises when liquid biosolids are applied so that they adhere to forage/pasture crops and are subsequently ingested by livestock used as human food. Smith [61] too considers uptake of OCs via direct ingestion of sludge adhering to grass and/or sludge-treated soil by grazing livestock and subsequent accumulation in animal as the main route of human exposure from agricultural use of sludge. However, he summarizes that the total human intake of identified organic pollutants from sludge application to land is minor and is unlikely to cause adverse health effects.

Eljarrat et al. (2008) investigated the fate of polybrominated diphenyl ethers (PBDEs) in sewage sludge after agricultural application and found elevated levels at soils 4 years after the last sludge application, indicating persistence of PBDEs in soils, including deca-BDE-209. Thus, although abiotic sorption may limit the potential for human exposure to PBDEs in soil, plants may increase the exposure risk by taking up and translocating PBDEs into above-ground tissues and by enhancing bioavailability in soil. There are few standards regarding PBDE-contaminated land. As to the [85] standard for penta-BDE in residential soil warranting preliminary remediation is 120 mg kg^{-1} DM, and for deca-BDE the standard is 610 mg kg^{-1} DM, however these do not consider potential human health effects. Standards or guidelines for PBDEs which are specific to different land uses (agricultural, playgrounds, commercial) are needed to protect human health.

For LAS risk ratios were identified to fall within a range of 0.01 (median LAS concentration in sludge) to 0.1 (95th percentile) and always below 0.5 (maximum LAS concentration measured in sludge) according to various scenarios covering different factors such as local sewage influent concentration, water hardness and sewage sludge stabilization process. Based on the present information, it can be concluded that LAS does not represent an ecological risk in Western Europe when applied via normal sludge amendment to agricultural soil [27].

As a matter of fact, the monitoring of OC will always be done much later than the emission of a substance. Scientists will never be able to "exclude an unacceptable risk," even when applying very expensive analytical single substance analyses because effects like, e.g., synergy effects cannot be assessed by such approach. Fürhacker [63] thus suggested an effect-based approach. In this approach the negative effects which shall be avoided are traced. It will be necessary for all stakeholders to agree on test methods and target effects and acceptable ranges for the effects in the biotests. With this also the effects of complex samples, additive or synergistic effects of mixtures and the metabolite question could be covered.

4.3 RA Pathogens

The risk of pathogen transmission from sewage sludge into human, animal or plant receptors is a major concern, and is reflected in regulations and codes of practice. In the past this threat has caused a significant reduction or complete ban of agricultural use. Risks of animal, plant and human infections were recognized, although there was a lack of clear evidence that for recorded outbreaks of salmonellosis in animals, sewage sludge was the route of infection, as most routes for infection were within existing agricultural activities. The only clear evidence for transfer of disease from sewage sludge has been in a few instances where its application has not been properly implemented or where operators may have been using unhygienic practices.

The most recent WHO guidelines for the use of wastewater and feces recommend a paradigm shift from water quality standards to health-based targets which could be achieved along a chain of risk-reduction barriers [50]. According to the Guideline, the basis of human health protection is that the additional disease burden due to viral, bacterial and protozoan diseases, which results from working in wastewater-irrigated fields, land application of sludge and excreta, and consuming wastewater-irrigated crops, should not exceed 10^{-6} disability-adjusted life year (DALY) loss per person per year (pppy). The combination of standard quantitative microbial risk analysis techniques are used to determine the minimum required pathogen reductions for restricted and unrestricted irrigation which ensure that the risks are not exceeded. For unrestricted irrigation the required pathogen reduction is 6–7 log10 units and for restricted irrigation 3–4 log10 units. For both restricted and unrestricted irrigation pathogen reduction of 3–4 log10 units has to be achieved through wastewater treatment processes post. In the case of unrestricted irrigation this has to be supplemented by a further 3–4 log10 units pathogen reduction obtained by post-treatment, pre-ingestion health protection control measures, pathogen die-off between the last irrigation and consumption and produce washing in clean water. Wastewaters used for both restricted and unrestricted irrigation also have to contain not more than one human intestinal nematode egg per liter [50].

To protect human exposure to microbiological contaminants, land application sewage sludge must meet risk-based pathogen limits. An indication of level of concern as specified by reuse/recycle guidelines USEPA (EPA Part 503) and some Member States of the EU is shown in Table 6.

To assess the health risk of pathogens associated with sludge reuse, quantitative microbial risk assessment (QMRA) method has been implemented by many researchers [65, 66]. Gale et al. [65] applied Quantitative Microbial Risk Assessment (QMRA) to assess human exposure to a range of pathogens from sludge applied to land subsequently used to cultivate a range of agricultural crops. Generally, the risks were found to be low although a number of uncertainties were recognized, particularly regarding the lack of reliable data on the long-term decay characteristics of pathogens in the environment.

EPA used risk-based standards to establish the chemical regulations, but for pathogens it used operational standards intended to reduce the presence of pathogens to concentrations that are not expected to cause adverse health effects.

The nature and concentration of pathogens in wastewater and sewage sludge is directly related to the incidence of enteric infections within a community and size of the population in the catchment [53]. Primary, secondary and tertiary sludges normally are combined, and the resulting mixture, which contains from 1 to 4% solids, is called "raw" sewage sludge. Because of its pathogen content and its instability, decomposable nature, raw sewage sludge is a potential health and environmental hazard; however, several treatment processes are used to stabilize sewage sludge, decrease its pathogen content and increase its solids content.

Effective barriers against the transmission of diseases are required. These can be either appropriate efficient treatment methods with high disinfection capacities or a specification of microbial quality or guidance on application targets.

Table 6 Microbiological quality guidelines and standards for application of wastes to agricultural land [52, 64]

References	Reuse conditions	Helminths	Fecal coliform	Salmonella	Enteric virus
[52]	Land application of manucipal sewage sludge class A	≤1 ova/4 g	<1,000 g^{-1} DM	<3 MPN/4 g DM	1PFU/4 DM
[52]	Land application of manucipal class B sewage sludge	NR	<2 × 10^6 g^{-1} DM	NR	NR
Denmark[a]	Land application		<100 g^{-1} Fecal Streptococci	No occurence	
France		3/10 g DM		8MPN/10 g DM	3MPN/10 g DM
Finland (539/2006)			<1,000 g *E. coli* cfu	ND in 25 g	
Italy				1,000 MPN/g M	
Luxembourg		No eggs	100 g^{-1} Enterobacteria		
Poland				No application	

NR no standard recommended, *MPN* most probable number, a form of estimation of bacterial numbers, *PFU* plaque forming units, a form of estimation of virus numbers, *MPCN* most probable cytophatic number, *DM* dry weight (dry matter), *ND* not detected

[a]Applies to advanced treated sludge only

5 Sludge Disposal Options

Due to lack of proper technology and poor economy, developing nations are still struggling with problems regarding sewage treatment, inadequate sanitary infrastructure and dilemma with the selection of the appropriate treatment system [67]. For example, in Egypt, for many years the methods and technologies of sewage sludge treatment implemented were very limited, and attention was devoted to the process of sludge drying, mainly through natural drying beds without any interest of the characteristics or quality of the produced sludge [14]. The establishment of an integrated and effective sludge management needs the commitment of those sectors involved in the development and enforcement of the regulations as well as those that are directly related to its generation, treatment, reuse or disposal. Following the ban on ocean dumping currently there are limited sludge disposal options which includes: land application, incineration and land filling. This paper focuses on sewage sludge land application.

5.1 Land Application

The final disposal of sewage sludge is a major component of the overall treatment costs, thus environmentally sound, economically feasible and socially acceptable alternative disposal options should be considered. The worldwide regulation of sludge recycling and safe disposal is a complex topic, since there are regions (continents) with Directives followed by national regulations, and others are with plain recommendations or no regulations at all. In the EU, the Urban Waste Water Treatment Directive 91/271/EEC (UWWTD) as amended by 98/15/EC defines more stringent quality standards for waste waters. Article 14 of the UWWTD specifically deals with sludge generated from waste water treatment. Sludge should be beneficially recycled whenever appropriate. In addition, Article 14 also required Member States to ensure that by 31 December 1998 the disposal of sludge to surface waters is phased-out [78]. In the US, U.S. EPA established Standards for the use or disposal of sewage sludge, i.e., rule 40 CFR Parts 257 (Classification of Solid Waste Disposal Facilities and Practices) and 503 (Standards for the Disposal of Sewage Sludge), which established legally binding requirements for municipal sludge when applied on land, distributed and marketed, placed in sludge-only landfills, or incinerated [51, 52]. Generally in the absence of standardized wastewater treatment one cannot expect regulations regarding sludge disposal. Nevertheless, some countries of the Middle East and North Africa have adopted WHO, EU or EPA regulations. Thus, agricultural land application appears to be a logical and reasonable use of sewage sludge, which is effective as a fertilizer to increases yield of many crops. Apart from its beneficial agricultural use, sewage sludge land application has been used as an excellent way for the reclamation of degraded soils, i.e., to improve soil physical properties such as porosity, aggregate stability, bulk density, and water retention and movement [3, 68]. This practice has been widespread in many countries around the world, for example, in the European community; over 30% of sewage sludge is used as fertilizer in agriculture.

The debate on sludge land application is constantly increasing across Europe and shows that the relationship between farmers and their customers, the food industry and retailers is of vital importance for accepting sludge use in agriculture. The advantages and disadvantages caused by land application of sewage sludge have attracted the attention of environmental authorities, the public and scientists [86].

5.1.1 Sewage Sludge Treatment for Land Application

Treatment of the contaminated sludge to reduce the concentrations of potentially toxic chemicals (inorganic and organic) and pathogen levels will promote the potential for reuse of the sludge with social [69] and technical obstacles [70].

Sewage sludge is usually processed to reduce its water content, its fermentation propensity and pathogens content. Sludge treatment considers the following steps: conditioning, thickening, dewatering, stabilization and/or disinfectant and thermal drying. Typical sludge treatment processes include: biological (digestion), chemical (lime treatment) and physical (high temperature drying). Some of the most important treatment methods for pathogen inactivation are presented in Table 7.

To further reduce the pathogens the following treatment processes were recommended by EPA [52], which includes:

1. *Composting* – sewage sludge is maintained at 55°C or higher for 3 days.
2. *Heat drying* – sewage sludge is dried by direct or indirect contact with hot gases at a temperature of 80°C.
3. *Heat treatment* – liquid sewage sludge is heated to a temperature of 180°C or high for 30 min.
4. *Thermophilic aerobic digestion* – liquid sewage sludge is agitated with air or oxygen with mean cell residence time for 10 days at 55–60°C.
5. *Beta ray irradiation* – sewage sludge is irradiated with beta ray from an accelerator at dosage of at least 1.0 megarad at room temperature (20°C).
6. *Gamma ray irradiation* – sewage sludge is irradiated with gamma rays from certain isotopes, such as cobalt 60 and cesium 137, at room temperature (20°C).

Where sludge is to be used on land, it is usually stabilized by mesophilic anaerobic digestion or aerobic digestion and then treated with polymers and mechanically dewatered using filter presses, vacuum filters or centrifuges. Generally aerobic stabilization has a more pronounced positive effect on the toxicities of sludges as compared to anaerobic stabilization, with the municipal sludges showing no or negligible toxicity after aerobic stabilization. Other treatment processes for sludge going to land include long-term storage, conditioning with lime, thermal

Table 7 Treatment processes to significantly reduce pathogens [52, 53, 71]

Treatment type	Description
Facultative lagoons and storage	Sludge is treated or stored in a lagoon system at a temperature of ≤5°C for a period of at least 6 months or at a temperature of >5°C for a period of at least 4 months. Because all wastes must be in a lagoon for the specified period, two lagoons probably will be needed so that while one is filling, the other can be aging. This avoids short-circuiting
Air-drying	Sludge is dried on sand beds or on paved or unpaved basins. The sludge dries for a minimum of 3 months. During two of the three months, the ambient average daily temperature is above 0°C
Composting (in vessel, static aerated pile or windrows)	The batch to be kept at a minimum of 40°C for at least 5 days and for 4 h during this period at a minimum of 55°C. This is to be followed by a maturation period to complete the composting process
Anaerobic digestion	Sludge is treated in the absence of air for a specific mean cell residence time (i.e., solids retention time) at a specific temperature. Values for mean cell residence time and temperature shall be between 15 days and 35–55°C and 60 days at 20°C
Aerobic digestion	Sludge is agitated with air or oxygen to maintain aerobic conditions for a specific mean cell residence time (i.e., solids retention time) at a specific temperature. Values for the mean cell residence time and temperature shall be between 40 days at 20°C and 60 days at 15°C
Lime stabilization	Sufficient lime is added to the sludge to raise the pH > 12 and sufficient to ensure for a period of 2 ≥ h of contact
Liquid storage	Storage of retreated liquid sludge for a minimum period of 3 months
Pasteurization	The temperature of the sewage sludge is maintained at 70°C for 30 min or longer

drying and composting. All these have different pathogen removal or inactivation characteristics, which vary from the relatively modest capability of mesophilic anaerobic digestion to reduce measurable *Escherichia coli* concentrations by 100-fold with significant variation in effectiveness, to the substantially complete inactivation of vegetative cells achieved by thermal drying. Variants of treatment methods that include thermal stages and multiple barriers to inhibit short-circuiting enable greatly improved reliability and confidence in the expected pathogen content of treated sludge. With the treatment processes a control and monitoring philosophy has to be developed that identifies critical control points in a process and the environment to ensure quality without unacceptable hazards to public health. Treatment processes for sludge should be managed according to the principles of HACCP (Hazard Analysis and Critical Control Point management) to provide assurance that the microbiological requirements are set out and met by appropriate risk management and reduction measures.

Periods of prohibition between sludge spreading and grazing or harvesting are another way of risk reduction. In the EU these periods vary between EU Member States, i.e., sludge must be spread at least 3 weeks before grazing or harvesting and on soil in which fruit and vegetable crops are growing, or at least 10 months for soils where fruit and vegetable crops that are eaten raw are cultivated in direct contact with soil [64]. This framework can be regulated in guidance documents and codes of practice to control use and operations.

5.2 Incineration

Incineration is another sludge treatment option that involves the combustion of sewage sludge at high temperatures in an enclosed structure. In the EU a new Directive on sludge incineration was issued in December 2000 [72], and currently incineration is considered as one of the most attractive treatment method. The future role of incineration is expected to increase due to the increasing legal limitations concerning agricultural reuse as well landfill is at its phase-out stage [73]. When incineration is considered as an alternative sludge treatment option, technology and cost are the major limitations. To be economically feasible, incineration must be done autothermically – i.e., sufficient water must be removed by mechanical dewatering so that the sludge will burn without the use of support fuel [74]. Despite the high cost, incineration has several advantages which can be summarized as follows:

- Maximum sludge volume reduction
- Reduction of the sludge mass to approx. 40% of its original dry weight
- Thermal destruction of pathogens and toxic organic chemicals

This disposal option does not have a high level of public acceptability due to concerns over pollutant emissions, and gaining consent to construct new incinerators is often difficult [70]. The shortcomings of sludge incineration are: sophisticated systems are required which makes it an expensive option for sewage sludge treatment and the potential benefits from organic matter and plant nutrients in sewage sludge are lost.

After incineration approximately the remaining ash which is stable, relatively inert, inorganic material (Lundin et al. 2004) is most commonly landfilled. In most cases the ash has to be treated as hazardous waste as most trace metals presented in the sewage sludge become concentrated in the ash. On the other hand ash produced from sewage sludge incineration has high phosphorus content, thus incineration of sewage sludge with subsequent recovery of phosphorus is a relatively new sludge treatment technique. Leaching with acid and base is a promising method for phosphorus recovery from the ash and slag that remain after combustion before entering a set of ion exchangers (Lundin et al. 2004). These potential benefits, delivered by widespread adoption of phosphorus removal, recovery and recycling practices, would appear to be a useful complement to more traditional (often locally targeted) controls on nutrient emissions in sewage effluents, sewage sludge and from agricultural practices [75].

In contrast to the common practice of phosphorus recover by (acid or base) leaching, in a recent research work, Adam et al. [76] investigated the applicability and effectiveness of thermo-chemical treatment in laboratory-scale rotary furnace by treating sewage sludge ashes under systematic variation of operational parameters: type of chloride (Cl) donor ($MgCl_2$ and $CaCl_2$, respectively), Cl-concentration (50–200 g Cl kg^{-1} ash), temperature (750–1,050°C) and retention time (20–120 min). The results revealed that heavy metals can be effectively removed from sewage sludge ashes by a thermo-chemical treatment. At a temperature of 1,000°C, the heavy metal contents were within the legal limits of Fertilizer Ordinances of European countries.

5.3 Landfill Disposal

Traditionally landfill disposal of sludge has been the most widely used and lowest cost method of sludge disposal. Owing to its poor physical nature sewage sludge should be well stabilized and dewatered before disposed to a landfill. Nevertheless, landfills produce waste products in three phases: solid (degraded waste), liquid (leachate) and gas (e.g., CH_4) [77]. There is no doubt that disposal through landfilling of sludges is not protective enough and thus has been already banned in most European countries. The EC Landfill Directive (1999/31/EC) requires all Member States to develop national strategies to reduce biodegradable wastes going to landfill.

6 Conclusion and Recommendation

The diversity of processes for sludge treatment has increased dramatically. There are still only three ultimate disposal routes for processed sludge: land application, landfill and/or technical use after incineration. Increasingly, governments and international regulating bodies are limiting the amount and quality of sludge that can be spread on land. The recent EU regulation is eliminating sludge disposal in landfills. Also, less-developed countries are not willing to spend the required investment and running cost for sewage sludge incineration. Land application is increasingly regarded as an insecure handling route by the public general and politicians although it is economically feasible, represents a sustainable and environmentally sound option for safe sludge handling, provided that the levels of contaminants in sludge are within the valid EU standards.

Regulations for OC are not consistent between EU and US, while US did not set limits, some European Countries did; nevertheless, reasonable actions to limit and prevent contamination with organic micropollutants that may cause harm to health or the environment are recommended.

To enhance the sustainability of sewage sludge land application, effective treatment options for pathogen reduction, source control and pretreatment of industrial wastewater also in terms of metals reduction should be implemented in combination with a quality assurance system and quality criteria of the sludge and the related products (e.g., compost) including product registration and labeling before placement on the market are also recommended. In case land application is not feasible or available land is limited or the sludge quality is off-limit, incineration in combination with the recovery of phosphorus through chemical treatments (e.g., leaching) or co-combustion in cement kilns is an alternative for the management of sewage sludge.

The treatment options have to be adapted to local situations based on socio-cultural, technological, economical and geographical conditions.

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Constraints of Application of Wastewater Treatment and Reuse in Mediterranean Partner Countries

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Abstract The scarcity of water and the need for protecting the environment and natural resources are the main factors leading countries in the Mediterranean region to introduce the reuse of treated wastewater as an additional water resource in their national plans of water resource management. In Mediterranean Partner Countries (MPCs), treatment and reuse of wastewater have already been applied to a certain extent, but there is still great scope for extending these practices.

This chapter aims to identify and discuss factors, which act as constraints to the broader application of treatment and reuse practices and technologies in MPCs. The report largely concentrates on the reuse of wastewater for the purpose of irrigation, which is the most common reuse activity in MPCs.

The key types of constraints reviewed in the report are the following: Financial constraints; Health impacts and environmental safety; Standards and regulations; Monitoring and evaluation; Technical constraints; Institutional set-up; Political commitment; and Public acceptance and awareness.

This chapter also illustrates how certain types of constraints have been recognized and dealt with in practice, by means of specific good practice examples from *Tunisia* (on national political commitment and farmer involvement), *Jordan*

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(on standards development and national political commitment) and *Egypt* (on grey water treatment in rural areas using low-cost systems).

Despite progress in some cases, further action and research is needed to address the factors currently limiting the application of these technologies in MPCs. The chapter thus puts forward a set of recommendations on priority actions and research needed. Priority recommendations concentrate on the aspects of financing and cost recovery, political commitment for treatment and reuse in the context of national water policies and ways of mitigating risks on public health and the environment.

Keywords Constraints, Re-use, South mediterranean, Treatment, Wastewater

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1 Introduction

Countries in the Middle East and North Africa are characterized by more repetitive periods of drought and irregularity of rainfall. It is predicted that chronic scarcity of water will be reached by 2025 along with further degradation of the water resources quality. The scarcity of water resources and the need for protecting the environment and natural resources are the main factors leading countries in the Middle East and North Africa to introduce the reuse of treated wastewater as an additional water resource in their national plans of water resource management [1].

On the one hand, in Mediterranean Partner Countries (MPCs),[1] treatment and reuse of wastewater have already been applied to a certain extent, particularly,

[1]Mediterranean Partner Countries (MPCs): Algeria, Palestinian authority, Egypt, Jordan, Israel, Lebanon, Morocco, Tunisia, Syria and Turkey.

Tunisia and Jordan are the MPCs with the highest wastewater reuse rates. On the other hand, it should be mentioned that even though planned reuse of treated wastewater is not a common practice in several MPCs yet, the unofficial use of raw wastewater is quite common, e.g., in Morocco or as indirect use of drainage water in Egypt.

Several factors still act as constraints to the broader application of treatment and reuse practices and technologies in the region of Mediterranean basin. Against this background and the arising need to review current constraints on treatment and reuse, this chapter aims to:

- Review and summarize key factors that act as constraints to the application of wastewater treatment technologies and practices of reuse in MPCs.
- Illustrate ways to deal with and possibly overcome key constraints by presenting some good practice examples from different regions and projects in the Mediterranean.
- Highlight key further action and research needed to support further treatment and reuse in MPCs.

This chapter mainly concentrates on the reuse of wastewater for the purpose of irrigation, which is the most common activity in MPCs. However, it should be kept in mind that wastewater can also be used for other purposes, e.g., industrial reuse, environmental reuse, potable reuse and others.

The sources of information used include reports from national projects, especially from countries participating in the INNOVA-MED project. Also reports from European-funded projects in the MPC region provided valuable information, especially EmWATER (Efficient Management of Wastewater treatment and reuse, financed by the MEDA Program) and the MEDAWARE Program (Euro-Mediterranean Regional Water Program for Local Water Management) under the MEDA Regional Indicative Programming. In addition, literature from internationally funded projects was taken into consideration, such as information from the WaDImena collaborative project on water demand management (funded by the International Development Research Centre, Canadian International Development Agency and International Fund for Agricultural Development) and the comparative study of the FEMIP Trust Fund – through the European Investment Bank – examining the current reuse of wastewater in selected countries of southern Mediterranean.

2 Key Constraints to Treatment and Reuse

Table 1 provides an overview of the most relevant constraints to the treatment and reuse of wastewater in MPCs. The overview of constraints, which is further elaborated in the sections that follow, is based on existing literature (e.g., [2–4]) as well as expert discussions within the INNOVAMED project.

As made obvious in the following, some types of constraints are closely interrelated, for example concerns about health and environmental impacts are

Table 1 Key types of constraints to treatment technologies of wastewater (WW) and reuse of WW

Type of constraint	WW treatment	WW reuse
Financial constraints (e.g., funding, cost-recovery issues, crop marketing)	√	√
Health impacts and environmental safety	–	√
Presence and enforcement of standards and regulations	√	√
Monitoring and evaluation of technology/scheme	√	√
Technical constraints	√	√
Institutional set-up and personnel capacity	√	√
Policy and political constraints	√	√
Public acceptance and awareness	–	√

linked to the issue of standard formulation and enforcement as well as effective monitoring.

2.1 *Financial Constraints*

In several cases in the Mediterranean basin, wastewater is not treated properly because the construction cost of efficient treatment systems is very high, especially for small- and medium-sized communities [3]. Advanced wastewater treatment technologies are even more expensive than conventional ones.

In addition, the initiation of treatment plants depends first on the establishment of a sewerage network. In Morocco, for instance, the cost of financing sewerage networks makes future treatment plants seem illusory [5]. Similarly, in Palestine, lack of funds for sewage collection systems is reported as a key problem [6].

Furthermore, in Morocco 60% of activated sludge treatment plants are out of order, due to the expensive cost of electricity, the absence of equipment maintenance and the lack of coordination between different contributors in the management of these plants [4].

In this context, it should be noted that involving the private sector as a financier in wastewater reuse projects is not common in the region, which can be attributed to unattractive economic prospects linked to (1) high capital requirements, (2) stringency of quality standards, (3) weak regulatory and enforcement systems, (4) low cost recovery and (5) price setting for reclaimed wastewater and freshwater by governmental decree, with a strong tendency to keep tariffs low [2].

The high investment and operational costs related to the collection and treatment of the influents, as well the conveyance and distribution of the treated effluents lead to the fact that reclaimed wastewater itself is often a financially expensive water source [2]. For instance, in Morocco, freshwater is still favoured over reclaimed wastewater as it is very cheap, thus giving no financial incentives to reuse wastewater [7]. In Tunisia, incentives were introduced to encourage farmers to utilize reclaimed water through cost reductions. The cost of one cubic meter of reclaimed water was approximately US$ 0.015 per cubic meter compared with US$ 0.0818 per cubic meter charged for freshwater supplies (in 1998). However, farmers still preferred to use freshwater to avoid restrictions imposed by reclaimed water reuse [8].

Also investment costs for the conception of irrigated areas with treated wastewater can be high, for example in Tunisia it is estimated at 10,000 TD/ha [5]. Thus, subsidizing reuse systems may be necessary at the early stages of system implementation, particularly when the associated costs are very large.

A general socio-economic constraint in MPCs is that the population does not pay high enough fees for wastewater treatment and drinking water services to cover the operation and maintenance costs of total expenses. For instance, residential users in Egypt (who account for ca. 80% of average system use) pay currently only ca. 35% of operation and maintenance costs of sewage treatment plants, and nothing towards the capital costs. The capital costs of wastewater treatment plants (WWTPs) in Egypt are presently financed mainly through donor grants and loans [5].

Also, in Jordan and Tunisia, the water price that farmers are willing to pay for reclaimed wastewater hardly covers the operation and maintenance costs for its conveyance and distribution. However, ambitious attempts to recover the full cost of treatment, conveyance and distribution might not succeed according to [29]. Among major factors that reduce farmers' willingness to pay for reclaimed wastewater are "worries about health impacts," "crop marketing," "and distrusted water quality," and the "availability/accessibility to fresh water at low price." On the issue of crop marketing, treated wastewater is usually not suitable for crops that are most economically profitable such as vegetables. Indeed, the list of crops where reused water can be applied is restricted (usually to hay). Cropping restriction/freedom is thus one of the most important factors that influence the decision of farmers to irrigate with reclaimed wastewater [2].

2.2 Health Impacts and Environmental Safety

According to Fatta et al. [3], concerns for human health and the environment are the most important constraints in the reuse of wastewater.

It is frequently the case that sewage treatment plants in MPCs do not operate satisfactorily and, in most cases, wastewater discharges exceed legal and/or hygienically acceptable maxima. The reason for this does not necessarily lie in the treatment plants themselves, but in the frequent lack of adequately trained technicians capable of technically operating such treatment plants.

Irrigating with untreated wastewater poses serious public health risks, as wastewater is a major source of excreted *pathogens* – bacteria, viruses, protozoa and helminths (worms) that cause gastro-intestinal infections in human beings [9]. Inappropriate wastewater use poses direct and indirect risks to human health caused by the consumption of polluted crops and fish. Farmers in direct contact to wastewater and contaminated soil are also at risk [10]. Reuse of wastewater in agriculture may also lead to livestock infections.

Increasingly, wastewater in the Mediterranean region is also loaded with other substances, such as heavy metals, which must be removed for the reuse of wastewater as well as different trace pollutants, including organic and inorganic compounds and emerging contaminants, such as pharmaceutical substances. Also dissolved inorganic constituents, such as calcium, sodium and sulfate, may have to be removed for wastewater reuse [11, 30].

In environmental safety terms, unregulated and continuous irrigation with sewage water may lead to problems such as soil structure deterioration (soil clogging) resulting in poor infiltration, soil salinization and phytotoxicity [12]. For instance, in Jordan salt levels in the soil tended to increase in some areas irrigated with wastewater, which was related to the salinity of wastewater as well as to on-farm management. Salinity implies that a certain number of less resistant crops cannot be irrigated by wastewater [3].

In Tunisia, the main environmental quality constraint to the reuse of wastewater is the excess of nitrogen.[2]

Potential environment impacts from the reuse of wastewater in agriculture also include groundwater and surface water contamination as well as natural habitat and ecosystem deterioration.

In Morocco, in some plants wastewater undergoes only secondary treatment and hence treated wastewater does not comply with the standards for wastewater reuse in agriculture [3]. Furthermore, although the irrigation of vegetable crops with raw wastewaters is forbidden, the ban on this is not respected which makes the consumer of agricultural products and the farmer face risks of bacteria or parasite contaminations.

A pilot project in Morocco examines the issue of industrial discharges into the sewerage network, which constitutes a constraint on the quality of treated wastewater (ultimately to be reused in agriculture). Industrial discharges should be pretreated to reduce the industrial pollution load reaching the WWTPs.

2.3 Standards and Regulations

An important element in the sustainable treatment and reuse of wastewater is the formulation of realistic standards and regulations. “Realistic” implies that standards must be achievable and the regulations enforceable. Unrealistic standards and non-enforceable regulations may do more harm than having no standards and regulations, because they create an attitude of indifference towards rules and regulations in general, both among polluters and administrators. For instance, the cost of treating wastewater to high microbiological standards can be so prohibitive that in some cases the use of untreated wastewater is allowed to take place unregulated [3].

[2]Reported during participants’ discussions at INNOVA-MED Course on Innovative Processes and Practices for Wastewater Treatment and Reuse, 21–24 November 2007, Hammamet, Tunisia.

Without question, the enforcement of microbiological guidelines or crop restrictions remains important, but a better balance between safeguarding consumers' (and farmers') health and safeguarding farmers' livelihoods should be made, especially in situations where the required water treatment or agronomic changes are unrealistic [12].

Usually, the makeup of standards and regulations is based on other international practices. Particularly, most of the wastewater reuse standards in the Middle East and North Africa region are based either on United States Environmental Protection Agency (USEPA) or on World Health Organization (WHO) guidelines [10] (see Box 1). Zimmo et al. [31] provide a detailed discussion of available wastewater reuse standards for Egypt, Jordan, Lebanon, Palestine, Greece, Turkey, Tunisia, Cyprus, Spain and Morocco.

In general, there is need for establishing milder standards and guidelines that take into consideration the scheme- and country-specific conditions. A set of inclusive guidelines should be established that enable establishing site-specific standards for each irrigation scheme [2]. Also, additional treatment (up to tertiary level) in certain cases to remove crop restrictions would help change farmers' attitude, because it would allow them to grow cash crops (vegetables) [12].

Attention should, however, also be paid to cases where existing regulations are not adequate to deal with the reuse activities taking place. For instance in Egypt, strict direct reuse standards are set in the Code of Use and the types of crops that can be irrigated with treated wastewater are very limited. However, none of these strict regulations are applicable for the indirect reuse of wastewater via agricultural drainage canals, which is a common practice in Egypt. Here, relevant laws only regulate the standards for discharge into agricultural drainage canals. In practice, the effluent quality of many treatment plants and direct dischargers does not comply with these standards. In addition, no restrictions of the crops irrigated with drainage canal water are stipulated [13].

Box 1 WHO Guidelines for Wastewater Reuse

The WHO started to develop guidelines for the sound use of wastewater already in 1973. These guidelines were updated in 1989 and most recently in 2006 (third edition of guidelines for the safe use of wastewater, excreta and grey water in agriculture and aquaculture).

The WHO guidelines are based on the so-called Stockholm framework, which emphasizes the assessment of health risks before the elaboration of risk management, namely, the setting of health-based targets and the creation of guidelines. The WHO guidelines include insights on policy, legislation, institutional frameworks and regulations. This comprehensive approach allows setting priorities, involving different stakeholders and facilitating communication of information between groups.

The 2006 WHO guidelines outline key criteria for the sustainability of projects in wastewater reuse. These are:

(1) health, (2) economic feasibility, (3) social impact and public perception, (4) financial feasibility, (5) environmental impact, (6) market feasibility, (7) institutional feasibility and (8) technical feasibility.

All in all, these criteria ensure that projects are adjusted to different communities and contexts and remain therefore sustainable.

The 2006 guidelines also set standards and reduction goals for pathogens and chemical contaminants and give recommendations for reduction measures to achieve human health and environmental health. In fact, the third edition of the WHO guidelines (of 2006) has been extensively updated to take account of new scientific evidence and contemporary approaches for risk management. The revised guidelines reflect a strong focus on disease prevention and public health principles.

Source: [15].

2.4 Monitoring and Evaluation

In several cases, the outflow of wastewater treatment systems does not meet standard quality either because standard operating procedures are not followed or because there is no qualified personnel to control and monitor the whole treatment procedure. The competent authorities in most of the countries in the Middle-East and North Africa region are currently not capable of being aware at all times of all data and information concerning the treatment plants. A prerequisite for the control and monitoring of all the activities taking place in relation to treatment and reuse, which is currently absent, is trained personnel of the authorities and the operators [3].

Also in the case of wastewater reuse systems, in many Mediterranean countries, the aspects related to monitoring and evaluation programs are irregular and not well developed. This is mainly due to weak institutions, the shortage of trained personnel, the lack of monitoring equipment and the relatively high cost required for monitoring processes. However, ignoring monitoring evaluation parameters and/or performing monitoring irregularly and incorrectly could result in serious negative impacts on health, water quality and environmental and ecological sustainability. In addition, it is important to introduce appropriate technical and organizational measures to systematically warn managers of wastewater reuse of breakdowns that may occur in the WWTPs, to avoid the flow of untreated wastewater into the distribution network [12].

2.5 Technical Constraints

A key technical constraint to wastewater treatment and reuse technologies in MPCs is the insufficient infrastructure for the treatment of wastewater [4] to produce safe treated wastewater. In Morocco, for instance, insufficient wastewater collection and treatment lead to a low percentage of wastewater suitable for reuse (only 13% of wastewater is considered as treated). In general, sanitation coverage in the Mediterranean region remains inadequate, particularly in rural areas [8].

In addition, engineers and decision-makers in this region tend to stick to the few technologies that they know – activated sludge, trickling filter and lagoon systems – and do not have exposure to wide varieties of technologies. In other words, authorities responsible for wastewater treatment may lack information on appropriate treatment technologies. Moreover, it should be considered that activated sludge technologies are expensive, which often means that countries barely recover operation and maintenance costs of wastewater treatment for these technologies [2]. In general, a large part of the technology transferred to MPCs for wastewater treatment does not actually work in practice due to high costs for proper operation and the lack of qualified technical personnel.

As far as the design of existing WWTPs is concerned, it can be an obstacle for the agricultural reuse of wastewater. Most of the existing WWTPs in the Middle-East and North Africa region were designed for environmental protection, and reuse was rarely considered in their planning and implementation. Even when reuse has been considered, assessment of the actual needs of the reclaimed wastewater users is often limited. Moreover, the nutrient content in the reclaimed wastewater has rarely been considered in the design criteria for WWTPs as well as in setting up the quality standards and regulations for wastewater reuse [2].

An additional constraint to waste water reuse is the limited availability of infrastructure for the conveyance and distribution of the treated effluent, especially, where the infrastructural requirements are high and the financial resources are limited. For instance in Tunisia, the treatment plants are generally far from the irrigated areas and this fact is one of the constraints to higher reuse rates [5]. Using the reclaimed wastewater in the vicinity of the WWTPs as far as possible overturns this disincentive and makes wastewater irrigation more attractive [2].

Some additional technical constraints to the reuse of wastewater reported in Tunisia include the great variability of wastewater quality provided by different treatment plants, the lack of storage basins for inter-seasonal storage of wastewater to be reused as well as the high content of suspended solids in treated wastewater, which cause many clogging problems [5].

2.6 Institutional Set-Up and Personnel Capacity

Weaknesses of the institutional set-up and poor coordination at intra- and intersectoral levels are another factor limiting the spread of wastewater treatment and reuse in the Mediterranean region. Planning, design, implementation, operation and maintenance of wastewater treatment and reuse facilities are usually distributed among many governmental departments, while coordination and cooperation between these bodies is lacking [2]. For instance in Morocco, the administrative structure concerning the reuse of wastewater is complex and includes no less than eight different offices or departments that are involved directly or indirectly [4].

Also, conflicts between different institutional actors involved in the process of treating and reusing wastewater may act as a constraint. In Tunisia, for instance, the main obstacle to further improvements in the rate of wastewater reuse is an institutional conflict over standards of wastewater treatment between the Ministry of the Environment, which is in charge of treatment standards, and the Ministry of Agriculture, which is in charge of wastewater reuse. According to the Ministry of Agriculture, the quality of treated wastewater must be improved, because current quality standards are not suitable for micro-irrigation and drip irrigation systems; to apply these irrigation techniques, it is necessary to reduce suspended solids in the treated irrigation water. However, the Ministry of the Environment supports the current standards of quality related to the existing secondary treatment [14].

In Palestine, the efficient financial and technical management of treatment plants and associated facilities requires strong institutional support. At present, the institutional responsibilities for wastewater management in the West Bank are not well defined, generally due to the overall absence of significant wastewater infrastructure. In addition, there is a weak networking system for the exchange of information and available data [6].

To plan, design, construct, operate and maintain treatment plants, appropriate technical and managerial expertise must be present. This requires the availability of an adequate number of engineers, access to a local network of research for scientific support and problem solving, access to good quality laboratories and monitoring system and experience in management and cost recovery. In addition, all technologies, including the simple ones, require devoted and experienced operators and technicians, with extensive education and training [12].

However, in the Mediterranean countries, few governmental agencies are adequately equipped for the tasks of wastewater management. Unfortunately, a considerable number of WWTPs in MPCs but also Mediterranean EU countries are not being operated due to lack of appropriate expertise and/or high costs of operation.

Ultimately, the lack of knowledge of plant operators on efficient operation, control and monitoring has an impact on the quality of treated effluents and subsequently poses risks to human health and the environment.

At the same time, public utilities, which are frequently in charge of wastewater treatment and reuse, are often expected to contribute to the alleviation of unemployment by hiring and keeping a large number of low-qualified staff. In addition, public utilities are subject to civil service salary rules, which restricts their ability to attract and maintain highly qualified personnel that is essential to the successful performance of key technical and managerial functions [2].

2.7 Policy and Political Constraints

The lack of political commitment and of a national policy and/or strategy to support wastewater treatment and reuse also acts as a constraint in certain MPCs.

For instance in Morocco, next to financial constraints and the missing awareness of public authorities, there is lack of a national policy in the field of wastewater management with the aim to protect water resources. In fact, with assistance from international organizations, Morocco launched several projects and experiments on wastewater treatment and reuse with significant results. However, in spite of the acquired experience, wastewater treatment and reuse projects have achieved only little progress in practice, due to the above-mentioned constraints [5].

In Palestine, wastewater reuse projects in the West Bank are also associated with political obstacles, next to financial, social, institutional and technical ones. First, the wastewater reuse concept is still tied to the political issues regarding the Palestinian water rights, because Israel considers reused wastewater as part of the total Palestinian freshwater rights. Second, an integrated vision for wastewater reuse issues is missing, which should include among others political and institutional aspects, water policy, awareness, marketing and tariffs [6].

2.8 Public Acceptance and Awareness

Limited involvement of local farmers, civil society and the private sector is also amongst the major factors that limits the growth of wastewater reuse [2].

There is a strong argument that farmers' involvement in all phases of a reuse project increases the opportunities for sustainability, reduces the managerial and financial burden on government institutions and, most importantly, improves the willingness of farmers to use and pay for reclaimed wastewater [2].

Farmers need to be informed about the health risks related to the use of wastewater and about the appropriate management procedures. In addition, farmers need to be convinced that treated wastewater can provide an attractive resource and that they can save money through reducing the application of fertilizers.

The involvement of crop consumers is at least as important as they are the ultimate financiers for the treatment and reclamation of wastewater and they are the potential consumers of irrigated crops [2]. Linked to that is the need to understand how the crop marketing system operates. The study by Abu-Madi [2] revealed that consumers often cannot distinguish between crops irrigated with freshwater and reclaimed wastewater. The existing system for crop marketing in which reclaimed-water crops are on offer together with freshwater crops is a good incentive to farmers to use reclaimed wastewater. Unfortunately, however, such marketing systems might tempt farmers to irrigate with raw untreated wastewater. Therefore, the crop marketing system has to be monitored to safeguard public health. The effects of the presence on the market of crops irrigated with reclaimed wastewater needs further study.

Responsible agencies have an important role to play in providing the concerned public with a clear understanding of the quality of the treated wastewater and how it is to be used, with confidence in the local management of the public utilities and the application of locally accepted technology, and with assurance that wastewater reuse involves minimal health risks and detrimental effects on the environment. In this regard, the continuous exchange of information between authorities and public representatives ensures that the adoption of specific water reuse program fulfils real user needs and generally recognized community goals for health, safety, ecological concerns program, cost, etc. In this way, initial reservations are likely to be overcome over a short period [12].

3 Dealing with Constraints: Lessons from Practical Examples in MPC

This section illustrates how certain types of constraints have been recognized and dealt with in practice, by means of specific examples from the Mediterranean region. The examples draw both on contributions of the INNOVAMED partners and current literature, and they reflect lessons learned from past and ongoing projects and activities.

3.1 Tunisia: National Reuse Strategy and Public Participation Efforts

Tunisia is one of the developing countries, which has developed the use of treated wastewater in irrigated agriculture for more than 30 years. The treatment sector has undergone continuous development that permitted the setting up of a planned infrastructure of facilities [14]. Approximately 24% of treated wastewater effluent is used for irrigated agriculture. Tunisia has also taken action to mitigate environmental and health risks associated with untreated wastewater use more than elsewhere in the world [10].

The following sections indicate that the practice of wastewater reuse in Tunisia has enjoyed political support for its nation-wide establishment. In addition, attempts have been made (and succeeded), at least in one irrigation scheme, to involve farmers from the early stages of project planning and implementation. However, experience from other regions of Tunisia show that further efforts still need to be made in terms of education and participation of local communities and end-users of wastewater.

3.1.1 Strategy and Policy to Promote Reuse

The relative success of reusing wastewater in Tunisia is related to political interest to support this activity. Since 1998, treated wastewater reuse was the subject of increasing political interest expressed within large subsidies provided within the water pricing policy (20% of the full price) to promote treated water reuse. Besides, a presidential decision was established in December 1999, aiming to coordinate all sectors for treated water reuse. The agricultural sector remains the most important field of reuse and an ambitious program was prepared within the forward development plans to reach 14,000 ha irrigated with treated wastewater [5].

Given the mobilization of almost all conventional water resources by 2010, the exploitation of non-conventional water resources, such as treated wastewater, is one of the main focal points of the Tunisian national strategy for water resources mobilization [5].

ONAS (National Sanitation Utility) has been in charge of preparing a national strategy for the improvement of treated wastewater. The study for this national strategy was completed in 2002 and aimed at identifying different treated water demands, reducing losses, protecting conventional water resources, maximizing socio-economic advantages from non-conventional water (e.g., by removing restrictions imposed in the case of irrigation) and minimizing environmental risk (especially the risk reduction in pollution and eutrophication due to excessive nitrogen) [5].

The strategy of treated wastewater reuse proposed some suitable answers to the national context of water resources and notably to regional specificities. The main objective is the increase in the rate of reuse from just above 20% to 40–60% according to the use sector [5]. In the following, there are some key proposals of the national strategy for the sector of agricultural irrigation, which remains the key sector of application of wastewater reuse in Tunisia.

Crop restriction is the most important issue that often leads to farmers' reticence. In Tunisia, wastewater is mainly processed up to a secondary treatment stage and is used for restrictive irrigation. Farmers are in search of safety and favourable conditions to ensure better valorization and higher incomes. The improvement of treated wastewater quality and removal of restrictions could lead to large-scale acceptance by farmers. Thus, complementary treatment or disinfection has to be developed.

Also, the lack of information on potential health risks, related to wastewater reuse and impacts on crops and soils, discourages farmers. Treated wastewater salinity and the high cost of hydraulic facilities are other constraints, which also obstruct the development of the sector and limit projects profitability [5].

Information campaigns for farmers have to be extended and advice needs to be provided on the nitrogen content of treated wastewater, which can largely substitute mineral fertilizer supply.

In addition, generalization of the treated wastewater use in arboriculture, associated with micro-irrigation systems and the use of subsurface irrigation techniques should increase the number of crops, which can be irrigated with treated wastewater.

Lessons Learned

The case of Tunisia shows how political commitment and the inclusion of wastewater treatment and reuse in the national strategy for water resources can promote treatment and reuse in an MPC. Political commitment has been expressed in form of subsidies for treated wastewater within the water pricing policy, the passing of relevant presidential decisions to support this activity as well as the preparation of a national strategy for the improvement of treated wastewater use to propose answers suitable to the national context of water resources as well as regional specificities.

3.1.2 Participation of Farmers in Wardanine Reuse Irrigation Scheme

The participatory approach with regard to wastewater reuse projects is likely to support safer and more efficient use of reclaimed wastewater as well as to maximize the reuse rate. This approach was successively applied in the Wardanine reuse scheme of Tunisia. In this scheme, farmers were involved from the early stages of the project planning and implementation in 1996. A water user association was formed representing 25 farmers that irrigate with reclaimed wastewater. This association was headed by a committee of seven elected members. The main tasks of the committee at the implementation phase were to [2]:

- Contribute to the construction of the project by solving design and operational difficulties between the contractor and the local population.
- Contribute to the opening of new agricultural roads.
- Help in selecting the sites for reservoir and pumping station.
- Coordinate between the equipment providers and the farmers.

After 5 years of project implementation, the main tasks of the farmers' committee were to [2]:

- Supervise the distribution of the reclaimed wastewater: The irrigation scheme utilizes 800–1,000 m/day, which is the entire treated effluent from the Wardanine WWTP that is 3 km away. There is a reservoir that has a capacity of 500 m and a pumping station adjacent to the WWTP. Approximately 95% of the reclaimed wastewater is used to irrigate fruit trees (mainly peaches and apricots) and only 5% irrigates fodders. However, due to the small capacity of the WWTP and reservoir, water is mainly supplied between 7 am and 7 pm, which is not practical and insufficient for irrigation that often occurs at night. Therefore, this is an unresolved point of conflict between the water users association and the Tunisian National Sewerage Agency.
- Collect water revenues from the farmers: The committee can use the collected revenues for operation & maintenance (O&M) purposes.
- Carry out certain O&M works, such as the cleaning of the reservoir.
- Represent the farmers with the Agricultural Bank for loans and subsidies.

Lessons Learned

The participatory approach facilitated the implementation and management of the reuse project but it also increased the willingness of farmers to use and pay for reclaimed wastewater. It has to be mentioned that the Wardanine reuse scheme is the only scheme out of the schemes surveyed by Abu-Madi [2] in Tunisia and Jordan, where an attempt was made (and succeeded) to involve farmers. Therefore, this example supports the argument that farmers' involvement in all project phases increases the opportunities for sustainability and reduces the managerial and financial burden on government institutions.

3.2 *Jordan: Reuse as Integral Component of Long-Term Water Resource Management*

Wastewater treatment has been given priority in Jordan for many years. Currently, more than 60% of the Jordanian population is connected to sewage systems. In addition, Jordan's desperate need for water has necessitated the reuse of treated wastewater in agriculture for many years [16].

All of the treated wastewater collected from the As-Samra WWTP, the country's largest plant treating the domestic wastewater of the capital Amman and of Jordan's second largest city Zarqa, is mixed with freshwater and used for unrestricted irrigation in the Jordan Valley. Thus, wastewater represents 10% of the current total water supply [10]. Jordan is reusing up to 85% of its treated wastewater [17].

The Jordan Valley is an area of low annual rainfalls (average of 100 mm to 300 mm per year) and agricultural irrigation consumes approx. 70% of available fresh water resources [18]. The effluent of the treatment plant As-Samra is first discharged into two consecutive wadis and temporarily stored in the King Talal Reservoir, being diluted with surface and precipitation water on its way, to irrigate approx. 11,300 ha of agricultural land [19].

The WWTP at As-Samra has been operational since 1985. In practice, diluted reclaimed water has been used for irrigation in the Jordan Valley since the mid-1980s. However, there had not been any binding guidelines or standards governing the agricultural reuse in the past, while there was increasing concern with regard to possible health hazards and environmental risks [20].

Growing public discussions and concerns regarding health and environmental aspects of reclaimed water use in the Jordan Valley led to the launching of action on behalf of the Jordanian authorities and international organizations.

3.2.1 Developing Standards and Guidelines for Health and Environmental Impacts of Reuse

To address the adverse affects of reclaimed water on soils and crops, the Jordan Institution for Standards and Metrology published the Technical Regulation Jordanian Standard 893/2002 on the use of wastewater for irrigation in agriculture [21]. Jordan was one of the earliest countries to adopt WHO and FAO effluent reuse guidelines for irrigation, which served as the basis for the Jordanian Standard. Its current version is the Jordanian Standard 893/2006 dealing with "Water-Reclaimed Wastewater" and "Domestic Wastewater." This Standard specifies the conditions that effluents from WWTPs should meet in order to be discharged into streams, wadis or water bodies or to be used for artificial groundwater recharge and for irrigation purposes [16].

However, the Standard 893/2002 did not cover the water quality of the receiving water once the reclaimed water had been discharged and blended with other water sources. In this context, the Reclaimed Water Project (RWP) was implemented in 2003–2006 jointly by the Jordan Valley Authority (JVA) and Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) with the support of the Jordanian and German Governments.

When the project commenced in 2003, the legal and institutional framework for the agricultural use of reclaimed water, especially of diluted reclaimed water applied for unrestricted agricultural irrigation in the central and southern Jordan Valley was not clear. There were no guidelines for blended reclaimed water or the quality of irrigation water in general. With regard to crop production, there were no safety guidelines for the occupational health of the irrigators, and there was no monitoring of the safety of fresh fruit and vegetables. Furthermore, there was no regular monitoring of the impact of the use of reclaimed water for irrigation on soils and groundwater [20].

As a first step, a baseline survey regarding the legal situation and the mandates of the involved organizations and stakeholders was carried out. With the help of national and international expertise, guidelines for irrigation water quality, crop quality and for monitoring and information systems were proposed. Interdisciplinary working groups adjusted the proposed guidelines to the conditions in Jordan and proposed applicable concepts [18].

Particularly, the proposed irrigation water quality guidelines were based mainly on the guidelines of the FAO [22] and WHO [32]. The proposal was approved by all relevant national authorities in 2004 and distributed and implemented during 2005. In 2006, the irrigation water quality guidelines were modified and revised by an interdisciplinary working group consisting of Jordanian authorities and universities. The modified guidelines were released in 2006 and take into consideration all water sources other than those mentioned in the Jordanian Standard 893. Furthermore, the guidelines cover all unrestricted agricultural crops. The modified guidelines also take into consideration regional and international regulations and standards. Furthermore, several international references were reviewed and adapted to develop guidelines appropriate to Jordanian conditions that can serve as the foremost guidelines dealing with irrigation water quality in Jordan [23].

The RWP also developed agronomic guidelines for the safe use of reclaimed water in the Jordan Valley [19]. Based on the intensive monitoring of nutrient contents of soils, reclaimed water and of the prevalent farming practices on more than 20 farms, one conclusion drawn was that reclaimed water provides plants with 20–40% of their total macro nutrient requirements. The agronomic guidelines were tested and implemented on-farm in cooperation with innovative farmers on 15 demonstration sites between 2004 and 2006. The project drew up fertigation sheets in Arabic language to be used directly by farmers. Previous surveys revealed that farmers in the Jordan Valley spend approximately 10.7 US$ million per season on buying commercial fertilizers. Considering the results of the monitored areas, it was shown that the reduction in commercial fertilizers according to the guidelines did not affect the yields. Particularly, P and K fertilizers could be reduced by up to 60% for some crops. Hence, farmers could save up to 60% of the fertilization costs, which is equivalent to US$ 770 per hectare [19].

In the area of public health, a state monitoring system for the quality of fresh fruit and vegetables under reclaimed water irrigation has been developed. As a first step, a national multidisciplinary working group was initiated in 2003 and elaborated a proposal for the monitoring program, including crop safety guidelines for Salmonella, E. coli, nitrate, lead and cadmium. In August 2005, a memorandum of understanding was signed by the JVA, Ministry of Health, Ministry of Agriculture, Jordan Food and Drug Administration, and the National Centre for Agricultural Research and Technology Transfer. The memorandum defines the responsibilities and the frame of commitments and implementation started in December 2005. In the harvesting period, random sampling of crops eaten uncooked from farms in the Jordan Valley irrigated with reclaimed water as well as from local markets in the Jordan Valley and Greater Amman is carried out. The samples are analyzed for Salmonella and E. coli as well as for nitrate, lead and cadmium [20].

With regard to environmental impacts, the first activity of the RWP was designing concepts for a groundwater monitoring program and a soil monitoring program. Based on the two concepts and results of sampling campaigns during the project, a combined long-term soil and groundwater monitoring concept was elaborated, introduced and discussed with Jordanian authorities and academics. The concept was accepted and implementation started in April 2006 [20].

3.2.2 Wastewater Reuse in Jordan's National Water Strategy

Due to Jordan's limited water resources, the Government of Jordan decided in 1997, as part of its Water Strategy, that "wastewater should not be managed as 'waste.' It should be collected and treated to standards that allow its reuse in unrestricted agriculture and other non-domestic purposes, including groundwater recharge" [20]. Thus, high priority was placed on the resource value of reclaimed water and Jordan was committed to a policy of complete reuse of treated wastewater effluents.

In 2009, the new National Water Strategy was published, formulating a number of goals which shall be achieved by 2022.

Agricultural irrigation and wastewater reuse will increasingly grow in importance, due to growing population, overexploitation of groundwater resources, and a reduction in precipitation. Hence, important goals for irrigation water are, inter alia, that all treated wastewater designated for irrigation shall be used for activities that demonstrate the highest financial and social return including irrigation and other non-potable uses. Wastewater reuse shall be used where the turnover is the most profitable. For the reuse of wastewater, a risk management system shall be introduced with treated wastewater standards accordingly [21].

In fact, wastewater reuse is also mentioned in the set of core principles of the Strategy:

> ". . . Jordanians must use water more effectively and efficiently and will use and reuse water wisely and responsibly . . ."

Among others, the Strategy puts forward the following approaches to further support wastewater reuse in irrigation [21]:

- Introduction of appropriate water tariffs and incentives to promote water efficiency in irrigation and higher economic returns for irrigated agricultural products managing treated wastewater as a perennial water source, which shall be an integral part of the national water budget.
- Ensuring that health standards for farm workers as well as consumers are reinforced and that all wastewater from municipal or industrial treatment plants will be treated in such a way that the effluent meets the relevant national standard.
- Periodical analysis and monitoring of all crops irrigated with treated wastewater or mixed waters.
- Designing and conducting programs on public and farmer's awareness to promote the reuse of treated wastewater, methods of irrigation, handling of produce.

Lessons Learned

In Jordan, wastewater reuse has become already an integral effective component of long-term water resources management.

An important step towards gaining *political support* was the inclusion of wastewater reuse in Jordan's National Water Strategy since 1997. This was a signal of placing high priority on the value of reclaimed water.

Jordan developed *national standards* on the use of wastewater for irrigation in agriculture to adverse public concerns regarding health and environmental aspects of reclaimed water use. Because water quality regulations and effluent standards are in place, water-borne diseases have been reduced in Jordan [24].

In addition, with the support of the Reclaimed Water Project (RWP), additional guidelines were developed and proposed for irrigation water quality, crop quality and for monitoring and information systems. This experience showed that it is vital to create the necessary awareness among the involved agencies, such as the key ministries and other stakeholders. It has proven efficient and successful to initiate national interdisciplinary working groups with specialists of the involved authorities for the elaboration of guidelines and monitoring programs [20].

Meanwhile, the prerequisites for a sound legal framework in Jordan for safe and environmentally harmless agricultural use of reclaimed water are in place. The implementation of monitoring activities has started and contributes to more transparency regarding health and the environmental impacts of irrigation with reclaimed water. What still needs to be done is to transform the guidelines effectively into standards and to ensure the subsequent implementation of the proposed monitoring programs and the enforcement of the recommended threshold values [20].

Furthermore, experience in Jordan revealed that it is not sufficient to intervene only in terms of the legal framework. Such action needs to be complemented by *awareness campaigns*. Certain studies carried out on farmers and their families' health and safety condition in the context of the RWP showed a necessity for awareness raising amongst those that will first be in contact with reclaimed wastewater.

3.3 Egypt: Grey Water Treatment at Village Level

Sanitation services in Egypt are less developed than those for water supply. Although urban coverage with improved sanitation gradually increased from 45% in 1993 to 56% in 2004, rural sanitation coverage remains very low at 4%. The low coverage, in combination with a sub-optimal treatment, results in serious problems of water pollution and degradation of health conditions because the majority of villages and rural areas discharge their raw domestic wastewater directly into the waterways. The discharges are increasing year after year due to the population growth as well as the rapid implementation of water supply networks in many villages without the parallel construction of sewage systems [25].

The main limiting factors for WWTPs at small community level are land availability, cost constraints including also costs for operation and maintenance and compliance issues with Egyptian standards [26].

In addition to the problem of sewage, villagers in Egypt also face the urgent problem of disposal of grey water (wash water, kitchen water, laundry water, and bath water) as illustrated in the following sections. This problem is the focus of the following two village case studies, where projects have been set up to treat grey water using gravel bed hydroponic systems.

3.3.1 El Nassria Grey Water Treatment Unit: A Case Study on Village Wastewater Collection

Background

The village El Nassria has a population of approximately 25,000 (mainly farmers); most of them are tenants of small pieces of land. The vast majority of the population is poor, with very limited income and education. The village is supplied with fresh water and electricity. It also has a health care unit, two primary schools, one preparatory school and an agricultural cooperative.

The village is deprived of some of the basic services, with special reference to wastewater treatment and solid waste management facilities. Such deprivation is manifested in the dirty narrow streets and alleys, where people dispose their wastewater and solid waste.

The Pre-Intervention Context

There is no wastewater treatment facility at the village, and houses are provided by some type of preliminary septic tanks for the collection of municipal wastewater. People are not willing to dispose their grey water into their municipal tanks, so as not to fill the tanks too soon and to have the trouble and cost of emptying them more frequently.

As a result, women tend to dispose grey water in the streets and in the fields. Street disposal of grey water poses a potential threat to people's health, especially for children spending long hours in the streets, as grey wastewater is a major source of diseases. Houseflies and mosquitoes swarm the areas where such water is disposed of, creating more problems and posing more threats to the community.

Technical Aspects of the Grey Water Treatment System

To deal with this problem, a grey water treatment system has been developed, which is made of seven water collection units, each of 70 cm height, covered with a screen that prevents solid waste to enter the collection tank. The collection tanks are located around the village streets, covering an equal area of the village.

Collected grey water is directed to a settling tank with a volume of 24 m^3 through a network of pipes and inspection chambers. The water in the settling tank is retained for 2–8 h before it moves to the gravel filter through a force main line. Finally, the treated wastewater is discharged into the village drain and ends up as an additional supply for irrigation.

Treatment Unit (Gravel Bed Hydroponic)

The gravel filter is 28 m long and 2 m wide, with a slope of 1:100 to allow water movement. The concrete structure is topped with layers of sand and gravel, 35 cm deep lined with a plastic sheet, 500 micron thickness.

Dense reeds are grown on the gravel. Reed roots are rhizomes that tend to expand and ramify within and beneath the gravel layer. The rhizomes provide a good support for a variety of microorganisms that enrich the gravel bed. The roots also provide the oxygen needed for the growth of these microorganisms to survive.

The biofilm formed by the combination of the microorganisms and the gravel system is the elemental factor that degrades pollutants and converts them into simple organic compounds, hence bringing the pollution load (biological oxygen demand) of the wastewater to acceptable levels. The system is provided with a weir to generate oxygen, a vital component for the microorganisms to thrive.

Financing the Facility

The main constraint in the planning phase of this grey water treatment unit on village level was lack of initial funding for the in-situ installed facilities. This was overcome by start-up financing by the Global Environmental Facility (GEF) to establish the facility. However, the operation of the facility is the responsibility of the inhabitants, thus an evaluation should be made if operation and maintenance costs can be adequately covered in practice.

Institutional Manageability and Administrative Capacity

The Women Society of Nassria (WSN) is a local association in charge of constructing and operating the grey water treatment unit. One of the main objectives of WSN is to make the connection between the Village Council and the treatment facility, whereby, the Council is sharing the supervision and management of the facility during operation. Meanwhile, the WSN is planning to hire two workers and one supervisor for troubleshooting and for ensuring the smooth running of the facility.

Raising Awareness

Once the idea of the project and the technique to be used was approved, a community-wide campaign was launched to introduce the project to the entire community and to mobilize them for the work to come. A number of meetings were held, in which some of the specialists and key officials have addressed the community. A number of senior governmental officers attended some of the meetings held at the village to answer the questions raised by the community members. Representatives of the Ministry of Water Resources and Irrigation, mosques, churches and members of the Village Council also attended the meetings. Most of the meetings concentrated on the impact of grey water on health, environment and economics. In addition, the need and potential to reuse this water and consider it a resource, as opposed to considering it as waste, was discussed. Some leaflets that sum up some of the advantages of the project and the need to implement it were produced and distributed. The campaign was well received by the community because grey water management is a need-driven demand. The awareness raising campaign was able to reach all sectors of the community.

WSN is also planning to hire four to five female environment specialists to help further mobilize the community, raise awareness and communicate with the community, giving guidance for the proper handling and management of grey water.

3.3.2 Gaafar Village Grey Water Treatment Facility: A Community-Based Approach

Sanitation and Grey Water at Gaafar

Gaafar village is deprived of wastewater treatment facilities. For some time, the vast majority of the houses were not provided with toilets. People had to defecate in the open, causing some serious health problems, especially for women who tended to refrain from defecation until late at night. In the meantime, community development organizations have provided many of the houses with toilets, and currently most of the houses have toilets. Most of the houses are provided with some type of septic tanks for municipal waste collection. However, these septic tanks are mostly bottomless allowing waste to infiltrate to groundwater, causing some serious pollution to groundwater resources.

In addition, grey water is one of the pressing problems in the village, next to municipal solid waste and excessive use of pesticides. The Gaafar women community considers grey water as their most important problem, because women often have to carry it for long distances to dispose it either in the drain or in the fields.

The Mahaba Society for Development and Environment (MSDE), a well-established non-governmental organization involved in a variety of activities on family care and helping out needy families, has organized a number of meetings that encompassed the whole spectrum of stakeholders to set the priority of the problems they face at Gaafar. The meeting had a good participation from community members, who rated grey water and solid waste as the most important problems that need an urgent intervention.

The Project of a Grey Water Treatment Facility

As answer to the grey water problem of Gaafar, a grey water treatment facility is being constructed which is based on a gravel bed filter grown with succulent reeds. As in the case of Nassria, grey water is collected in collection tanks, 70 m high, located at different parts of the village to cover various streets.

Grey water is then collected in a settling tank, 12 m^3, where water settles for 2–8 h. After the elimination of much of the suspended solids at the settling tank, water is driven through a force main line to the gravel bed filter, through a line of 500 m. The gravel bed filter is a concrete construction with two beds, each with a diameter of 2×50 m. Each bed is covered with a 25 cm layer of gravel, lined with a 5 cm layer of sand, with a plastic membrane of 500 micron thickness envelopes the gravel and sand layers. Reed roots are rhizomes that tend to expand and ramify underneath and beneath the gravel layer. The rhizomic roots provide a good support for a variety of microorganisms that enrich the gravel bed.

The system would be provided with a weir that would help generate oxygen, an essential component for the good performance of the gravel bed filter.

Institutionalization, Capacity Building and Awareness-Raising

The MSDE is planning to train one or two community members to supervise the facility and provide necessary troubleshooting measures when needed.

A program to raise awareness and to build capacity in the field of grey water treatment and the use of the gravel bed hydroponic system is being delivered to a number of villagers. The program would also include factors that affect the quality of the performance and efficiency of the gravel bed hydroponic system.

Stakeholder Involvement

One of the community members has donated a piece of land of approximately 350 m^2, on which the gravel bed filter would be built. The area is close to the drain that would receive the treated effluent, Shiekh Yehia drain. However, the cost of bed constructions, reeds and others is covered through the GEF. The construction of the system is carried out by a private contractor under the supervision of the Mahaba Society.

The contribution of other community members will be restricted to monthly fees, after the completion of the project. The fees will be used to pay the limited staff, which will look after the facility, including guarding, and troubleshooting measures.

Other stakeholders involved in the project include the Department of Public Health, Department of Water Resources and Irrigation, Department of Agriculture and Governorate Council.

Lessons Learned

Effectiveness of gravel bed hydroponic systems

Although both examples of gravel bed hydroponic system installation above have not delivered yet insights on the effectiveness of the system, the following lists some of the main system advantages [26]:

- Easy operation and reasonable capital cost.
- Excellent efficiency of removing pathogens at a level almost similar to WHO standards.
- High efficiency of removing nutrients, many organics.
- Effluent compliance with Egyptian regulations.
- Land requirements not ideal but could be afforded at village level.
- Effluent can be used straight for agriculture.

The efficacy of such biologically based system in treating wastewater is well established. Good performance of the unit depends on a number of factors that include:

- The dense and succulent growth of the reeds and their expanding root system.
- The diversity and richness of the microorganisms.
- The retention time of the wastewater in the structure.
- Bed length and gravel size.

It should also be kept in mind that microorganisms, the driving power for the system, are very sensitive to particular contaminants that could find their way to wastewater, such as phenols and cyanide. Nevertheless, in view of the domestic nature of the grey water, the possibility of such toxicants presence is rather low. However, such information should be passed on to community members for information purposes.

Need for monitoring

Early running of the gravel bed should be accompanied by a regular monitoring of the quality of treated wastewater. Samples of wastewater entering the system and samples of water discharged into the drain should have their COD, BOD, total suspended solids TSS, measured. Monitoring programs should be performed on regular basis to make sure that the system is performing satisfactorily. If poor performance is recorded, reasons should be ascertained to take necessary steps.

Factors that might contribute to inferior performance may include:

- Disposal of farm animal's excreta, due to its high organic load.
- Short retention time.
- Inefficient microorganisms.
- Poor root growth.
- Toxins in wastewater.

Financing, stakeholder involvement and awareness

The examples show that the funds for establishing these grey water treatment systems could be raised due to the relatively reasonable capital cost of the system. Costs for operation and maintenance are to be covered through community member fees, thus an evaluation should be made in due time whether these costs can be adequately covered in practice.

In both cases, the involvement of local association and non-governmental organizations was very important for initiating and organizing the construction of the system. In addition, awareness campaigns helped in mobilizing and informing the community about the advantages from correct operation of such a grey water treatment system.

Box 2 Highlights of the Gravel Bed Hydroponic System

- Gravel Bed Hydroponic (GBH) reed bed systems consist of channels sealed with geomembrane.
- The channels are filled with gravel and wastewater is percolated horizontally below the surface of the gravel. This subsurface flow reduces the potential for breeding sites of insects, especially mosquitoes and aquatic snails.
- Reeds, predominantly *Phragmites australis*, are planted in the gravel and grow hydroponically using nutrients in the sewage.
- The reeds maintain the hydraulic pathways and their rhizospheres support intense microbial activity which ensures sewage treatment.

4 Recommendations for Future Actions and Research

The Mediterranean population becomes increasingly urban; therefore, it becomes more important to ensure that urban wastewater receives proper treatment and is reused to permit additional uses. The current Mediterranean water deficits could be, in part, alleviated by the adoption of safe wastewater reuse programs. Therefore, further action and research is needed to address the factors currently limiting affordability, robustness and user acceptance of these technologies in Mediterranean environments.

This section formulates recommendations of the INNOVA-MED project for priority actions and research proposed, to overcome key constraints to treatment and reuse of wastewater and sludge in MPCs. The recommendations are structured along key types of constraints as identified and described in the section "Key constraints to treatment and reuse" of this chapter.

1. *Financing, cost recovery and marketability*

   – Funding needs to be secured for further facilities of wastewater treatment in MPC, also to produce treated wastewater, which is safe for reuse. New funding opportunities should be explored, e.g., future EU funding earmarked for the Mediterranean region with emphasis on sanitation and wastewater treatment improvement.
   – Efforts need to be made towards reducing the burden of heavy operation costs of treatment facilities. Considering that, in some cases, 75% of WWTP operation costs are due to electricity consumption, research results on possibilities to achieve electricity savings in operating conditions should be used in practice. Research shows that with certain changes in operating parameters, e.g., in terms of time of aeration periods, large savings in electricity can be achieved. Preconditions are knowledge of the operating system and of the appropriate modeling techniques; in this context, collaboration between the wastewater treatment industry and the academia is needed [27].
   – Operation electricity costs can also be reduced via State reductions in the cost of electricity supplied to treatment plants. For instance, in Turkey, the new Environment Act (under revision) foresees that the establishments (local authorities and industrial plants), which run a WWTP will be entitled to get 50% reduction in the cost of electricity that they use (Berber R. personal communication 2008).
   – Other ways to significantly reduce the operational electricity costs of wastewater treatment in MPC include the broader use of solar energy, due to the suitability of climate and weather conditions in these countries.
   – Next to costs for treating wastewater, also costs for the reuse of treated wastewater need to be recovered. It is argued that a fundamental element for sustainable reuse is the payment of a fee to cover costs of mobilization. This fee, however, would be substantial and regularly paid, only if the practiced agriculture is able to generate products of sufficient added value. Thus, it needs to be ensured that wastewater reuse is profitable to farmers for gaining acceptance as a practice. Specific research should be carried out on ways to extend the list of crops, which can be irrigated with wastewater (especially for well-marketable vegetable crops), e.g., by upgrading treatment technologies and the quality of wastewater and/or by applying irrigation systems with absence of contact between water and the product to guarantee hygienic quality.

2. *Political commitment*

   – The reuse of treated wastewater in MPC needs clear political support and the development of appropriate strategies in the context of a country's overall water resources policy to promote this practice. Commitment to reuse should be part of the proclaimed water policy and strategy in all countries of the Mediterranean region, particularly those suffering from water scarcity.

3. *Mitigating health and environmental risks (including standard development and monitoring)*

   – Carry out adequate treatment of wastewater – well accepted treatment processes need to be listed, in combination with their removal potentials.
   – For accepted treatment processes, easy to measure parameters should be developed e.g., temperature measurement for thermal treatment, oxidation-reduction potential (ORP) for anaerobic or aerobic processes or pH for lime treatment.
   – The relevant process parameters shall be monitored at least daily, and preferably continuously if practicable. Records shall be kept and made available upon request to the competent authority for inspection purposes and/or for customers.
   – The processes shall be initially validated by log10 reduction with test organisms.
   – Control wastewater outlets in the network.
   – Industrial wastewater should be pretreated to domestic wastewater quality levels prior to discharge into public sewers. This should help avoid many complications in the treatment and reuse of wastewater.
   – Common guidelines (ISO standards) should be developed on the operation of wastewater treatment facilities in MPC.
   – Promote the use of streamline life cycle analysis in the field of wastewater in MPC.
   – Monitor the contamination level in soil and crops irrigated with treated wastewater.
   – Monitor quality of groundwater where treated wastewater is used.
   – For an affordable monitoring system of the quality of water for reuse, it is proposed to limit the number of parameters to be monitored (e.g., to coliforms, helminths, salinity, pH, nitrogen).
   – As it is hard to keep the consumers' confidence and to cope with emerging contaminants, effect measurements should be considered besides chemical and pathogen monitoring data.
   – Use drip irrigation in water reuse, because it reduces considerably health risks.
   – Further research should be carried out on corrective measures for soil salinity and alkalinity, soil health protection and human health risk management. From the macro-scale analysis point of view, it is recommended for Mediterranean countries setting up demonstration and extension of the Best

Management Practices for saline and treated wastewater under different cropping systems.

- Common norms and standards for the reuse of treated wastewater in MPC should be established. So far, different MPC have taken different regulatory approaches with varying standards to manage the reuse of treated wastewater and sludge. In this context, it is important to comply with the framework criteria given in the WHO guidelines for the safe use of wastewater (latest version of 2006). The guidelines, however, also need to be adapted to local conditions for each Mediterranean country, to satisfy its own set of conditions. See also [31] for further recommendations on the development of water reuse guidelines for Mediterranean countries.
- Different levels of accepted quality (e.g., class I excellent quality, class II good quality, class III satisfying) will give incentives for an improvement in wastewater quality over time. Viable options based on different treatment levels for different uses of wastewater (including food and non-food crops, landscaping and groundwater recharge) but also of sludge should be assessed accounting for the parameters of the Mediterranean region and social acceptance.
- Quality standards need to be developed also for sludge, for its safe reuse and the safeguarding of soil quality, e.g., in terms of heavy metal concentration and pathogens. Especially, the effluent of industries needs to be monitored for heavy metals and Best Available Technologies (BAT) should be applied in industrial processes.

Code of good practice of reuse

- Beside obligatory requirements, it could be envisaged to set up codes of good practice for the use of wastewater and sludge in the different countries and for various applications. The codes should contain certain provisions for not impairing the quality of groundwater, the prevention of leaching from storage; selection of application periods in terms of weather conditions. In agriculture, the sludge shall be used when there is need for growing of crops, taking into account all the other fertilizers applied.
- It needs detailed plans for reducing the amount of potentially hazardous substances, materials, elements or compounds that end up in the sewer, and therefore in wastewater or sewage sludge because of their presence in cleaning products, detergents, personal care products, medicines, pipes, or others.
- Therefore, consumers should be informed of the composition of the products, substances or materials that could end up in the sewer and how to dispose of them in a way which does not pollute wastewaters.

Nitrogen pollution risk mitigation

- It is important to establish with high precision the water balance in the soil plant system, by quantifying the inputs (rainfall, irrigation volume) and the outputs (crop uptakes and evaporation).

- Nutrient contents should be analyzed, in particular, treated wastewater nitrogen. This will allow quantifying the amount of added nitrogen in the applied irrigation, considering the yield level to be achieved, to evaluate the nutrient uptake.
- Based on the soil analysis, the balance of mineral nitrogen remaining in the soil should be considered.
- The irrigation dose is an important factor that conditions nitrate leaching. Therefore, in light sandy soils, it is recommended to reduce the amount of water applied and increase the frequency. At this level, it is recommended to consider the importance of optimizing the rate of nitrogen and the irrigation water depth on the basis of crop water and nitrogen requirements for the different stages.
- Crops with high nitrogen uptake should be chosen and/or maximum soil crop cover should be assured.
- It is recommended to mix rich nitrogen waters and low nitrogen waters or alternate these two types of waters.
- It is also strongly recommended to establish a nitrogen mass balance, coupled with a water balance, to protect the aquifer against nitrate contamination. The objectives are to keep nitrate concentration in the water below 50 mg/l or to assure 0% annual increment rate in case the nitrate concentrations exceed 50 mg/l.

4. *Improving the technical setting*

   - It is recommended to select the most suitable treatment technology on case-by-case basis, based on the type of possible reuse of the treated wastewater. In a first step, it is proposed to select the appropriate irrigation system for a specific crop, keeping in mind that drip irrigation allows to reduce health risks from reused wastewater. As a second step, the appropriate wastewater treatment system should be selected.
   - Future research should focus on the development of affordable technologies, emphasizing biotechnologies for wastewater treatment and safe agricultural reuse in the Mediterranean. In addition, we should focus on innovative, appropriate and cost-effective technologies (and biotechnologies) for sludge treatment.
   - In the INNOVA-MED project, the following newly emerging technologies were identified and considered as innovative proposals to be used in wastewater treatment and reuse in MPC: Tertiary treatments such as advanced oxidation processes, biological treatments (advanced anaerobic treatment, membrane bioreactors, alternating anaerobic and anoxic treatments, etc.), chemical and biological integrated systems to reduce the operational costs of the treatment plant as well as wastewater reuse treatments (reverse osmosis systems, ultrafiltration and nanofiltration). However, it should be kept in mind that wastewater treatment systems are capital-intensive and require expensive and specialized operators. Therefore, before selecting a wastewater treatment technology in an MPC (including new techniques mentioned

above), an analysis of cost-effectiveness needs to be made and compared with all conceivable alternatives [28].
– A strategy for the inter-seasonal storage of treated wastewater should be developed in each country.

5. *Raising awareness and acceptance of reuse*

– The participation of end users of treated wastewater should be systematic already at the inception phase of a reuse project.
– Capacity building and training should be organized for farmers on how to use wastewater as well as on sanitary protection and health protection aspects.
– Awareness campaigns should be carried out educating on the danger of reusing raw wastewater and on the advantages of using treated wastewater. It is also necessary to communicate up-to-date information on appropriate processing and crop protection technologies to authorities responsible for wastewater treatment and reuse as well as the end users.
– To achieve positive perception of treated wastewater reuse and high level of compliance among users, demonstration activities are needed. Users and the public need to be well informed about the scientific facts of wastewater reuse and evidence of benefits in simple comprehensible ways; by means of demonstration, they should also be able to see the tangible results.
– For the consumer, it should be clear that the applied wastewater was treated appropriately, this needs to be ensured by monitoring programs which are accessible for the general public and supervised by special (trusted) authorities or independent experts.
– There should be a provision on producer responsibility and certification. Producers are to be responsible for and guarantee the quality of wastewater and sludge supplied. Producers should implement a quality assurance system for the whole process, i.e., control of pollutants at source, wastewater and sludge treatment, including the communication of information to the receiver. The quality assurance system shall be independently audited. The origin and the quality of the wastewater and sludge applied need to be known and shall be able to be traced back.
– A quality competition or benchmark system between suppliers could give further incentives to achieve excellent quality.

6. *Institutional coordination and strengthening personnel capacity*

– There is need for more qualified technical personnel and need for personnel training to achieve efficient operation of WWTPs. For instance, a new Environment Act in Turkey (currently being revised) foresees that WWTPs must maintain necessary technical staff and develop expertise for their operation. The new Act will also provide measures for training technical personnel, and creating an Environmental Management Unit in each of the respective establishments (Berber personal communication 2008).

– A close dialogue between institutions in the water treatment and reuse chain is necessary to co-ordinate and complete their respective efforts. This can be supported by encouraging cooperation benefits between different institutions.

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Life Cycle Analysis in Wastewater: A Sustainability Perspective

Mohamed Tawfic Ahmed

Abstract The use of wastewater as a source of water is emerging as one of the most sustainable alternative in view of global water scarcity. A variety of risks and threats are impeded in the use of wastewater, especially those related to public health and environment. Environmental management tools have been developed and used in the water industry including the production of potable water or for wastewater treatment with the prime objective of maintaining sustainability and curbing any hazardous impact that might affect consumers and alleviating the environment burden involved in this industry. In addition, a set of sustainability indicators were developed to help gauging sustainability issues in the water industry. Environmental impact assessment (EIA) and risk assessment (RA) are among the early environmental tools employed in the water industry with wide implementation in wastewater facilities and technologies. Despite the numerous advantages EIA and RA have added to the concept of sustainability and human safety, some shortcomings were also apparent that needed an additional tool to help overcome such gaps. Life cycle analysis, an ISO guided step wise process, is considered the most holistic tool that would encounter all upstream and downstream impacts related to the industry. It also offers the prospects of mapping the energy and material flows as well as the resources of the total system. On the other side, LCA tend to require copious sets of information and data that can limit its use in developing countries where information shortage prevails. The present part is focused on highlighting some of the main features of environmental sustainability of the water industry, along with the main tools applied to help promoting sustainability. It also delineate on life cycle analysis as one of the most comprehensive guidelines used in water industry towards the ultimate goal of achieving sustainability.

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1 Industry and Environment

Industrial growth and development, beyond doubt, are the major drivers of economic progress and societal prosperity. Industry has always been the nuclei that communities and civic activities cascaded around, allowing all other activities to develop and cherish. Industry is also one of the major causes for environmental degradation, resources depletions, and pollution [1].

In this respect, it is rather safe to state that the industrial revolution was the prelude of a massive perturbation in global ecological systems and natural imbalance. It was not until the early 1960s when people and authorities alike have become aware of the magnitude of damage inflicted on global environment, thanks to the early deliberation of environmentally sparked works of Rachel Carson and many others who unveiled the grim width of environmental damage. The colossal emission of carbon dioxide and other green house gases through industrial processing or energy used is the main cause for the unprecedented warming up and associated environmental changes that pose one of the most potential threats to Mankind.

With industry bringing effluence and prosperity, general patterns of human consumption and production have changed significantly. Population growth, improving standard of living, increasing personal interest to consume products and services have offset the limited efforts designed to safeguard environmental integrity, and to maintain its quality. The challenge was to conceptualize the growing pressure on the environment with its finite resources, the growing demand of current generations, and the legitimate needs for future generations to come. This challenge requires the adoption of novel strategies and a paradigm shift from a narrowly focused process management to a broader and more comprehensive management.

1.1 Sustainable Development

The concept of sustainable development has first emerged in the early 1970s to depict a new nut shell in which environmental integrity, ecosystem services, and present and future generations' needs were conceptualized to guide further development and industrial growth. The United Nations Conference on Human Environment held in Stockholm, 1972 [2] ushered the introduction of this concept along with the spectrum of related ideas. The concept of sustainable development has become a prominent common theme in many of the international meetings and functions organized by public and international bodies. The significant importance of sustainability stems from global recognition that present norms of economic development cannot be generalized, and present levels of developed countries per capita resource consumption cannot possibly be generalized to all currently living people, much less to future generation, without liquidating the natural capital on which future economic activity depends [3].

The United Nations World Commission on Environment and Development, presented the most widely accepted definition of sustainable development as " the development which meets the needs of the present generation without compromising the ability of future generations to meet their own needs" ([4], Our Common Future). Subsequently, several attempts to define the concept have been made. One definition which focuses more on environmental degradation defines SD as "improving the quality of life while living within the carrying capacity of supporting ecosystems" [5].

With the extensive over exploitation of natural resources, humanity has now entered into a state of global overshoot with demand for resources exceeding the Earth's regenerative capacity by more than 20%. Hence, the global biosphere now takes nearly 1 year and 3 months to regenerate what humanity uses each year [6]. Therefore, as Goodland and Daly [3] put it, the transition to sustainability is urgent because the deterioration of global life support systems – the environment – imposes a time limit.

2 Water

Water is one of the most important ecosystem services. Water is essential for life, and we are all aware of its necessity, for drinking, for producing food, and for washing. Clean water provides recreation, commercial opportunities, fish habitat, and adds beauty to our landscape. In essence, water is necessary for maintaining our humanity and dignity. Access to water is a basic human right (WHO, 2003)[1] and is a basic element for achieving other human rights. Water and sanitation have been included as an integral components in the UN Millennium Development Goals.

Global water use has increased by more than double the population increase.

Economic growth and increasing food needs are two main threats to future water supply through increased pollution and over consumption of water. Today, about one-third of the world's population live in countries experiencing moderate water stress, i.e., where the use of freshwater is greater than 10% of renewable freshwater resources [7].

2.1 Water Industry

Water industry has been one of the early established utility industries with the objective of providing clean and safe potable water to communities. Wastewater treatment industry is the other side of the coin that complements that industry, ensuring the safe disposal of waste water. Nevertheless, as much as wastewater facilities minimize the environmental impacts of wastewater, they, on the other hand, should be designed to reduce their total impact on the environment. This means that the whole life cycle of the system must be considered [8].

Both components of the water industry are multi procedural operational units that involve many raw materials, chemicals, in addition to electricity consumption.

2.2 Wastewater Treatment Facilities, Why Sustainability

Sustainability is a central concern in wastewater treatment station throughout the various stages such as construction, operation, and decommissioning. The operation stage poses the most potential threats, considering the diversity of pathogenic organisms, along with the different species of chemical pollutants that the

[1]25 questions and answers on health and human rights, WHO, undated WHO Library Cataloguing-in-publication data right to water. 1. Water supply 2. Potable water 3. Human rights 4. Treaties I. World Health Organization. Health and human rights publication series, no. 3. ISBN 92 4 159056 4 (NLM classification:WA 675) ISSN 1684-1700 http://edocs.lib.sfu.ca/projects/chodarr/documents/chodarr1194.pdf.

wastewater stream may contain. Communities must take great care when reusing wastewater; both chemical substances and biological pathogens threaten public health and accumulate in the food chain when used to irrigate crops or in aquaculture. Moreover, the traditional linear treatment systems must be transformed into the cyclical treatment to promote the conservation of water and nutrient resources. Using organic waste nutrient cycles from point-of-generation to point-of-production, closes the resource loop and provides an approach for the management of valuable wastewater resources. Failing to recover organic wastewater from urban areas means a huge loss of life-supporting resources that instead of being used in agriculture for food production are used to fill rivers with polluted water [9].

The environmental impacts of water industry are quite considerable. Most wastewater treatment systems require high level of energy to operate especially advanced treatment systems that use membranes. Intensive energy use may cause unforeseen problems for the site including increased energy costs and impacts on carbon generation.

Deslauriers et al. [10] indicated that more that 5% of all global electricity is used to treat wastewater. They also indicated that in the US wastewater treatment facilities are responsible for the emission of 1% of the total emission inventory of green house gases.

Energy costs can account for 30% of the total operation and maintenance costs of wastewater treatment plants [11]. Meanwhile, wastewater treatment plants would also account for approximately 3% of the electric load in the United States. Furthermore, as populations grow and environmental requirements become more stringent, demand for electricity at such plants is expected to grow by approximately 20% over the next 15 years [11]. Regarding GHG emission, in 2000, energy-related emissions resulting from public owned wastewater treatment works operations in the USA – excluding organic sludge degradation – caused a global warming potential of 15.5 teragrams (Tg) CO_2 equivalents (CO_2-eq.), an acidification potential of 145 gigagrams (Gg) SO^2 equivalents, and eutrophication potential of 4 Gg PO43 equivalents [12]. CH^4 and N^2O are emitted during organic sludge degradation by anaerobic bacteria in the soil environment, wastewater treatment plant, and receiving water body. In 2006, an estimated 23.9 and 8.1 Tg CO_2-eq. of CH^4 and N^2O, respectively, resulted from organic sludge degradation in wastewater treatment system, constituting over 0.5% of total U.S. GHG emissions (USA, [13]).

3 Sustainability of Water, Development of Indicators

Indicators are very important tools for the process of decision making, simplifying or summarizing important properties, visualizing phenomena of interest, quantifying, measuring, and communicating relevant information [14].

In general, an indicator is a piece of information which has a wider significance than its immediate meaning [15]. If an indicator relates to a criterion, an objective, or a target, it may be referred to as a performance indicator. If various indicators are combined into one, it is referred to as an index [15].

Growing demand for treated wastewater to augment freshwater resources in countries suffering water shortage, besides the need to minimize the risks of wastewater to environment have prompted a number of elaborated studies that focused on sustainability measures of wastewater.

The use of any particular set of indicators would depend on factors related to community culture, geographical aspects, end users, and other stakeholders. Several lists of sustainability indicators have been proposed to assess wastewater management and wastewater treatment technologies [16–19].

Balkema et al. [19] proposed a general assessment methodology that builds on multiobjective optimization and a complete set of sustainability indicators, yielding insight into the trade-offs made when selecting sustainable wastewater treatment systems. They pointed out to a number of indicators that include:

- Economic affordability of the treatment
- Global warm up and ozone depletion, toxicity to humans, and acidification
- Construction, operation, and maintenance requirements
- Adaptability to social, cultural, and institutional environment
- Resource utilization
- Biotic and abiotic depletion, desiccation
- Scale and possibilities for integration

Meanwhile, Lundin et al. [20] describes a framework for selecting Sustainable Development Indicators (SDI) for WWTP using LCA. He added that the use of a life cycle perspective to guide the selection of SDI would allow the development of an environmental decision-making approach at the municipal or company level for urban water systems.

- Balkema et al. [21] describes a framework for a methodology to compare a large number of different wastewater treatment systems on sustainability and LCA forms the basis for this methodology.
- Mels et al. [22] developed a set of sustainability criteria from LCA to evaluate sustainability of treatment plants, based on the following variables: energy balance, final sludge production, effluent quality, use of chemicals, and space requirement.

Lundin and Morrison [23] describe relative levels of environmental sustainability of wastewater systems as follows:

Level	Infrastructure characteristics	Organization characteristics
A	Clean technology, efficient resource reuse, source separation technologies, recycling of nutrients and water	Attempts to identify and adopt sustainable practice Proactive decision making
B	Ahead of standards for environmental compliance, but focus on compliance issues. Advanced end-of-pipe solutions	Legislative, financial and infrastructure restrictions. Concern over public perception

(*continued*)

Level	Infrastructure characteristics	Organization characteristics
C	Meeting minimum environmental standards and health objectives	Reactive decision making, reliance on consumer complaints
D	Not meeting human health protection objectives	Inadequate operation and maintenance. Inadequate cost-recovery. High rate of expansion

The move to level A is hindered by existing infrastructure as well as organizational constraints. There is a need for developing countries to leapfrog from level D to level A. LCA studies must be used to guide decision making in that respect.

3.1 The DPSIR Model

The use of the DPSIR (Driving forces, Pressures, State, Impact, and Responses) approach by UNEP and other international, regional, and national agencies around the world has become as a generic tool to support understanding of these complex relationships and reporting on them across the whole range of environmental issues.

The DPSIR model shows the connections between the causes of environmental problems, their impacts, and society's responses to them in an integrated way.

According to this model, there is a chain of causal links from driving forces, over Pressures to States and Impacts, finally leading to Societal Responses.

- **D**rivers are mainly economic and social activities (e.g., production of goods and services, leisure activities, etc.)
- **P**ressures on people and the environment. As a result of the pressures
- The **S**tate of the environment is affected. Changes in air and water quality, in land and forest areas, etc. These changes in state may than lead to
- **I**mpacts such as ill health, biodiversity loss, etc. These impacts finally lead to societal
- **R**esponses in the form of for example technical standards, economic instruments, environmental investment, increasing public awareness, etc. (Fig. 1, Table 1).

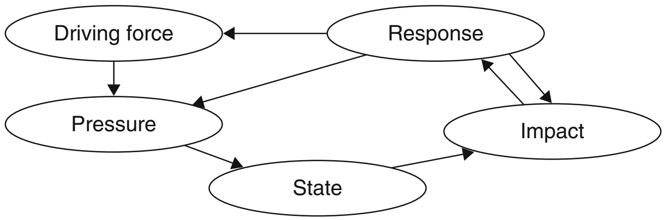

Fig. 1 The DPSIR model

Table 1 UNCSD indicators related to urban water systems placed in the driving force–state–response (DSR) model

Category	Driving force indicators	State indicator	Response indicators
Social indicators	Rate of growth of urban population	Access to safe drinking water and basic sanitation	Infrastructure expenditure per capita
Economic indicators	Annual energy consumption	Share of renewable energy Intensity of material use	Environmental protection expenditures as a percent of GDP
Environmental indicators	Annual with drawl of freshwater /annually available volume Domestic water consumption Population growth coastal areas releases N and P Use of fertilizers Use of agriculture pesticides Irrigated portion of arable land	Ground water reserves concentration of fecal coliform in freshwater BOD in water bodies Algae index	Wastewater treatment coverage expenditure on waste management Waste recycling and reuse Municipal waste disposal number of chemical banned or severally restricted

3.2 Environmental Systems

Environmental management involves a set of management processes and procedures that allow an organization to analyze and reduce the environmental impact of its activities.

The European Eco-Management and Audit Scheme (EMAS) is one of the most used systems that project to promote improvement in industries practices and norms towards environment was first introduced in 1993. EMAS was further revised in 2008 to encourage companies and industrial entities to participate in the scheme. EMAS objectives are to:

- Improve environmental compliance
- Improve environmental performance in nonregulated areas, such as energy and water conservation
- Increase the ability to identify pollution prevention opportunities
- Enhance operational control and efficiency
- Reduce costs
- Improve relationships with regulators

Environmental management systems represent the overall process set up by that entity to manage these effects, in the best possible practices. In the EMAS regulation, the environmental management system is defined as "that part of the overall management system which includes organizational structure, responsibilities, practices, procedures, processes, and resources for determining and implementing the environmental policy".

An environmental audit is a periodic control by external experts which has to state the effectiveness of the environmental management system. The scope of EMAS is initially limited to the factory gate, and then eventually it would include raw materials acquisition, transport, and distribution of the product and finally its disposal after it becomes a waste, hence illustrating a start of a link between EMAS and LCA.

In many cases, EMAS was used to develop a step-by-step workbook to help utilities use an approach to reduce energy use at water and wastewater facilities.

Many organizations – as diverse as metal finishers, pharmaceutical manufacturers, schools, federal agencies, and administrative office sites – have come to realize both the business and environmental benefits of an EMS.

4 Environmental System and Wastewater Treatment Facilities

With the growing demand for the re use of wastewater and the rising awareness of sanitation, an elemental component of human well being, wastewater treatment plants have increased in number. New technologies have emerged to improve the quality of treatments and to minimize associated risks. A number of environmental management tools have been used to safeguards environment and harness risks and impacts of wastewater treatment and application, with environmental impact assessment, risk assessment, and life cycle analysis as the most comprehensively tools used in this domain.

4.1 Environmental Impact Assessment, Definition, and Background

Many attempts have been made to define environmental impact assessment in ways which express the full extent of its role and purpose in environmental management. Perhaps the most comprehensive definition of EIA is that suggested by [24], adaptation of [25]:

EIA is a process for identifying the likely consequences for the biogeophysical environment and for man's health and welfare of implementing particular activities and for conveying this information, at a stage when it can materially affect their decisions to those responsible for sanctioning proposals.

The EIA process has been developing since the 1960s when it was first given formalized status through the USA's National Environmental Protection Act (NEPA), which required EIAs for federally funded or supported projects, likely to cause environmental effects.

Since the enactment of the NEPA, EIA have been established in a various forms throughout the world, beginning with more developed countries and later in less developed countries.

The objective of the EIA is to make sure that environmental problems are foreseen and well addressed by decision-makers, who are not normally deeply acquainted with the technicalities of an EIA report. Moreover, an EIA could be seen and reviewed by groups of laymen at one stage or the other, as part of a public consultation process. Hence, an EIA should be clearly presented in an unequivocal manner.

EIA has some limitations that tend to affect its status as one of the environmental management tools. One of the main shortcoming of EIA is that it is performed as a one time exercise, while the process of project design is cyclical and iterative. Moreover, EIA is often performed late in the planning process, usually after project proponents have become attached to a particular design concept. Under these conditions it is difficult to expect EIA to cause any changes in fundamental decisions regarding the types of alternative projects given serious consideration or project scale or location.

EIA has been used extensively in wastewater treatment plants as a planning tool to predict expected impacts, providing possible alternative that may include site, technology, energy used, or others. It also provides mitigation measures to expected impacts along with a plan to monitor implementation procedures. Requirements of EIA are imposed on countries that have no formal programs, because bilateral and multilateral aid agencies often call for EIAs on the project they fund.

4.2 Environmental Assessment and Uncertainty

At its early stages, EIA made no reference to human or environmental risk assessment. With the growing demand for EIA studies, uncertainty has emerged in environmental studies as a controversial issue, with no definite framework to contain. EIA studies extensively deal with parameters of relevant interest, formulated in terms of single figures, such as mean or worst – case value. For example, the concentration of a particular contaminant in water or air could be expressed as average part per million. If uncertainties are large and important, such as oil spill or dam failure, a single figure cannot be used to indicate the probability of such serious incidents. A more structured and reliable approach is needed to assess the probability and/or the frequency of such incident, hence paving the way to risk assessment. It was quite evident soon after that the need to assess risks associated with chemicals or gas emissions, failure of dams or other structure should be incorporated in the construct of EIA, and risk assessment was the answer to these question; hence, it became an integral part of EIA studies.

4.3 Risk Assessment and Risk Management

Some potential risks are embedded in wastewater industry, with special reference to wastewater treatment, discharge, and reuse. Because wastewater treatment process is a multi-procedural operation, it involves a different species of multiple hazards.

Risk assessment process, includes various steps that are meant to identify and evaluate risks, risk impacts, and would also highlight risk-reducing and risk mitigation measures. Risk assessment culminates in risk management a separate activity involving the process of evaluating alternative regulatory actions and selecting among them. Risk management is looked upon as an agency decision-making process that entails consideration of political, social, economic, and engineering information along with risk related information to develop, analyze, and compare regulatory options and to select the appropriate regulatory response to a potential health hazard. Using experience and judgment, the (risk) manager must determine a level of risk that is acceptable.

4.4 Life Cycle Analysis

The International Standards Organization (ISO) has defined LCA as: "A technique for assessing the environmental aspects and potential impacts associated with a product by:

- Compiling an inventory of relevant inputs and outputs of a product system
- Evaluating the potential environmental impacts associated with those inputs and outputs
- Interpreting the results of the inventory analysis and impact assessment phases in relation to the objectives of the study" (ISO 14.040)

The technique examines every stage of the life cycle, from the winning of the raw materials, through manufacture, distribution, use, possible reuse/recycling and then final disposal. For each stage, the inputs (in terms of raw materials and energy) and outputs (in terms of emissions to air, water, soil, and solid waste) are calculated, and these are aggregated over the Life Cycle. These inputs and outputs are then converted into their effects on the environment, i.e., their environmental impacts. The sum of these environmental impacts then represents the overall environmental effect of the Life Cycle of the product or service.

The provision of such holistic vision aids decision making and helps in the formulation of environmental strategy and policy [26, 27]. LCA can also be used to expose environmental trade-offs (e.g., a change in production may reduce air emissions but increase water emissions). In this way, LCA provides a stringent assessment of environmental sustainability.

LCA methodology goes beyond the quantification and evaluation of the environmental performance of a product or process to help decision makers to choose among alternatives, it provides a basis to assess the potential for improvements in the environmental performance of a system [26].

4.5 Life Cycle Analysis and Environmental Impact Assessment

The basic characterestic of EIA is its role to predict impacts caused by a project, producing a plan of action to prevent them if possible, or to mitigate them if avoidance is not feasible. There seems to be some considerable commonalities between EIA and LCA as they both adopt a systemic approach and they tend to integrate different environmental effects besides being based on a multi disciplinary approach. But on the other hand, some significant differences are also apparent between the two methods. For example, EIA is not oriented to address the product but mainly focused on the process of producing that product regardless to the life cycle of the production. Moreover, EIA looks at the project under study as if it were isolated from other activities in the life cycle. In this respect, it is safe to say that EIA is a more localized approach and site specific since real emissions and impacts on the local environment should be evaluated, while LCA is related to the evaluation of a more potential and wider impacts. Because EIA is concentrating on the local site, indirect and cumulative impacts are usually overlooked, especially those that affect other locations or those regional or global in scale. On the other hand, the standard LCA methods are not quite capable of detailing most local impacts [28].

4.6 Life Cycle Analysis and Risk Assessment

Both LCA and RA provide a way of structuring, presenting, and evaluating information relevant to one or more environmental aspects of the decision-making process. In addition, both approaches have a life cycle perspective; however, they differ in the way of viewing the life cycle. The procedure RA covers the whole life cycle of a chemical product/substance since all potential sources of emission of the product/substance should be included. However, if the chemical substance is converted to another substance (metabolite) during use it is not included in the risk assessment process.

In addition, in risk assessment, the main goal is to determine if a product or a substance is safe and under which specific conditions safety is secured. Main emphases are laid on effect–oriented approach with more focus on the consequences over the whole effect chain. In case of LCA, the effect chain is restricted to primary effects or potential effects.

A major difference that separates the paradigm of risk assessment from that of life cycle analysis is that risk assessment embraces two main components, namely the extent of damage and the probability of causing the damage. This paradigm would deviate from LCA since the data used in LCA tend to relate mass and energy balance during normal operation, while accidental emissions or accidents, which are considered as core issues of risk assessment, are not in the domain of LCA.

Further difference between the two management systems is in the way emissions of the studied compound is looked at. In LCA, emissions caused by the investigated product or service as specified in the defined functional unit is usually the mass of the product or is associated to the benefit and performance of the technical system. Results of the impact assessment are expressed in the form of numerical indicator, with the underlying information usually not related to space and time. While in RA, on the contrary, emissions are expressed as concentrations, e.g., mass of a product by volume in a specific environment.

Box 1 EIA Process

- Project/action identification: This will include an examination of alternatives such as processes and locations as well as the scale and dimensions of the project or action.
- Project screening: Determining whether the project requires EIA and deciding whether the scale or other factors can be reduced to avoid formal EIA.
- Scoping: Narrows down the scope of EIA to the most likely significant impacts and defines the environment to be assessed. This will include the geographical level of the study, i.e., local, regional, national, transitional, etc.
- Project/action description: A detailed description of the project or activity is assembled to ensure that all facets and, therefore, all potential impacts are identified.
- Baseline environmental conditions description: This requires a thorough investigation or audit of the environment into which the project is to be introduced.
- Identification of key or significant impacts: This is where the previous states are brought together to ensure that all significant impacts are identified. It should be emphasized that impacts can be both positive and negative.
- Impact prediction: Evaluation and assessment of the significance of impacts.
- Mitigation: The measures proposed to reduce the significance of impacts, including any redesign or reduction in scale of the project.
- Public participation and consultation: This should not be seen as simply taking place at this point in the process but ideally should take place continuously from the first stage onwards. Public participation and consultation with public bodies can be particularly crucial to the success of the scoping stage.
- Environmental statement preparation and presentation.
- Review: This is the more formal ES appraisal stage where the authorization body, together with the public and consultative bodies, consider the content, quality, and the methodologies contained in the ES.
- Decision making: The formal authorization stage will depend on the decision-making system and may require separate appraisal of other factors outside the remit of EIA such as national economic policies.
- Monitoring: The monitoring of the impacts as they take place during construction/operation.
- Auditing: Assesses the quality of the EIA process by comparing predicted and actual impacts.

Environmental Planning and Impact Assessment in Practices
Joe Weston [29]

5 Life Cycle History

The origins of the LCA methodology can be traced back to the late 1960s [30]. Initial studies were simple and generally restricted to calculating energy requirements and solid waste. In 1969, the Coca-Cola Company initiated and funded a study to compare and determine which container had the lowest release to the environment and the lowest consumption of material resources [31]. The process of quantifying the resource use and the environmental release became known as Resource and Environmental Profile Analysis (REPA).

During the oil crisis of the early 1970s, extensive energy studies based on Life Cycle Inventories (LCI) were performed for a range of industrial systems [32]. However, these studies were performed using different methods and without a common theoretical framework. Since 1990, attempts have been made to develop and standardize the LCA methodology under the coordination of the Society of Environmental Toxicology and Chemistry (SETAC) [33]. In 1993, SETAC published a "Code of Practice", which presents general principles and a framework for the conduct, review, presentation, and use of LCA findings. An international standard for LCA put together by the ISO has recently emerged.

LCA became vital to support the development of eco-labeling schemes which are operating or planned in a number of countries around the world. In order for eco-labels to be granted to chosen products, the awarding authority needs to be able to evaluate the manufacturing processes involved, the energy consumption in manufacture and use, and the amount and type of waste generated.

A key feature of LCA is that the system boundary is drawn "from cradle to grave," so that the inputs are primary resources and the physical outputs are the set of all flows to the environment. This integrative approach avoids substituting one set of environmental problems for an another set.

5.1 Why Perform LCA?

LCAs might be conducted by an industrial sector to identify areas where improvements can be made, in terms of the environmental. Alternatively, the LCA may be intended to provide environmental data for the public or for government. In recent years, a number of major companies have cited LCAs in their marketing and advertising, to support claims that their products are "*environmentally friendly*" or even "*environmentally superior*" to those of their rivals. Many of these claims have been successfully challenged by environmental groups.

At its early stages the main emphases of LCA were on its capability to guide decision-making process, but eventually it gained a wide spectrum application in a variety of fields. Jensen et al. [34] present some of these emerging applications as follows:

- Internal industrial use for product development and improvement
- Internal strategic planning and policy decision tool in industry

- External industrial use for marketing purposes
- Governmental policy making in areas of eco-labeling, green procurement, and waste management opportunities

Jensen et al. [34] have also pinpointed the three different levels of LCA suited for different applications. These levels are as follows:

- The conceptual LCA or life cycle thinking

This is the first and simplest form of LCA, mostly based on a simple scoring system. Conceptual LCA is most suited as an environmental tool used internally to illuminate day-to-day performance of a company, to help trace areas where improper decisions were made and the drawbacks of such improper decisions. Conceptual LCA is not necessarily made for publishing outside the entity.

- The simplified (or streamlined LCA)

Simplified LCA is used as an alternative to detailed LCA when the full spectrum of data required for a detailed LCA are not available. A simplified LCA would also need much shorter time than the detailed studies. Simplified LCA is a comprehensive LCA conducted to cover the full length of the system, but using quantitative and/or qualitative generic sets of data. It also includes a simplified life cycle impact assessment (LCIA) that may focus on particular stages of the life cycle where important environmental impacts are identified. Simplified LCA is usually presented as a matrix, in one axis representing life cycle stages, while the other represent environmental impacts and other attributes. The use of simplified LCA is increasing because of the simplicity of its application combined with the relatively small cost it needs. With such advantage in mind, there is a growing interest to standardize its framework and processes to promote its application and make more reliable.

- The academic, detailed LCA

This is a detailed assessment, in which fully quantitative and system specific life cycle inventory analysis are deployed in what is occasionally called "gate to gate study". It also should contain a LCIA of all important environmental aspects of the product or the service. A detailed LCA would require vast amount of data and time to perform, with high costs usually incurred.

6 Life Cycle Analysis and Wastewater

Growing concern about climate change and emissions of green house gases, have prompted the use of LCA as a tool for a better understanding of the contribution of wastewater in global warm up, and how to minimize such contribution. And, with the variety of techniques employed in wastewater treatment, the need for LCA as a comparison tool has become eminent. However, unlike EIA use in wastewater, which has become compulsory in some cases when international donors are involved, the use of LCA is still based on voluntary bases, and is mostly performed in developed countries. One reason of the limited use of LCA in developing countries is the extensive data requirements that LCA would need, and the inability of most of the developing countries to provide them. However, it was not before the 1990s when the use of LCA has been mainstreamed in various industries and services, including the field of wastewater industry. The variety of models and programs and other software developed and provided by expert houses have helped greatly harnessing the complexity and sometimes the ambiguity of LCA use and offered the proper logistic support for its application . The use of life cycle analysis in wastewater has contributed primarily in informing policies and decisions [35]. It can also help managing the diverse impacts emanating from the various stages of the wastewater right through the construction of the facility down to the demolition stage. LCA gives an ample view to the spectrum of impacts upstream the treatment process to the downstream segment where environment is most affected. With the spatial and temporal dimension LCA would provide a comparison of different methods and or scenarios based on chemical and energy consumption, quantity of sludge generation, emission of green house gases, capital cost (civil construction and mechanical installation), maintenance cost, and land requirements would be transparent and based on factual figures. There are an increasing number of LCA studies for water and wastewater entire systems, parts of systems or components such as pipes or chemicals. The magnitude of studies will increase the knowledge of the environmental impact from the systems but also on how to use LCA. Methodological experience has been gained on how to choose system boundaries and what parameters to focus on. One potential reason for the demand of LCA in water industry studies is the fact that LCA information are needed for the international trade specially for products exported to developed countries where much environmental information are basic requirements for products sold in their markets. Since water is an elemental component used in the production of a diverse list of products, it would be of paramount importance to display the profile of water used in the production processes as worked out by LCA. Equally important is to display the profile of wastewater generated in the production processes and treatment profile using LCA.

One other major advantage in applying LCA to evaluation of wastewater treatment is the full coverage of global and regional environmental impacts.

Research of LCA in wastewater extends mostly in developed countries with almost no contribution from developing countries. Roeleveld et al. [36], performed an LCA of different conventional wastewater treatment methods in order to assess the total environmental burden of these systems at a national level in The Netherlands. They concluded that in order to improve the sustainability of the systems, attention should be directed on minimizing the discharge of emissions from the effluent and minimizing sludge production. They also noted that energy use, construction, and the use of chemicals were less important compared to other activities. Emmerson et al. [37] performing a comparative LCA study of the environmental load of three small-scale sewage plants indicated that biofilters are much preferred than activated sludge, in spite of a higher material requirement due to less energy use and less emission to air.

With the growing interest in alternative sewage treatment technology, Dalemo [38] compared conventional treatment with urine separation and the environmental effects were evaluated through LCA. Tillman et al. [39] conducted an LCA focused on the consequences of a change in the existing wastewater systems in two Swedish municipalities and concluded an analysis of the environmental load of both the construction phase and the operation phase of the systems. The two alternatives were compared to the existing conventional system and a local treatment in sand filter beds and a urine separation system. Tawfic Ahmed [40] has presented an overview of the use of LCA in wastewater with special reference to its use in developing countries, and the difficulties that limit the use of LCA. Kirk et al. [35] have discussed sustainability of wastewater treatment facilities, including indicators and management systems employed. A comparative analysis of LCA, in comparison to EIA and other environmental management tools was presented and discussed.

6.1 Steps of Life Cycle Analysis

6.1.1 Goal and Scope (ISO 14041)

This is the first stage of the study and probably the most important, since the elements defined here, such as purpose and intended application, scope, and main hypothesis are considered key features of the study. In addition, the initiator should be mentioned in this section [41]. The scope of the study usually implies defining the system, its boundaries (conceptual, geographical, and temporal), the quality of the data used, the main hypothesis, and limitations. A key issue in the scope is the definition of the functional unit. This is the unit of the product or service whose environmental impacts will be assessed or compared. It is often expressed in terms of amount of product, but should really be related to the amount of product needed to perform a given function. The functional unit in one of the potable water production studies was defined as 1,000 kg of potable water at the quality stipulated in the region water guidelines produced over the life period of a process unit [42].

During the goal definition process, the following issues should be considered:

- Why is the study being conducted (i.e., what decision, action, or activity will it contribute to or affect)?
- Why is LCA needed for this decision, action, or activity? What, specifically, is it expected to contribute?
- What additional analytical tools are needed and what will they be expected to contribute?

- Who is the primary target audience for the study (i.e., who will be making the decision, taking or directing the action, or organizing or participating in the activity)?
- What other audiences will have access to the study results? What uses might these audiences make of the study findings?
- What are the overall environmental goals, values, and principles of the sponsoring organization and intended audience?
- How does the intended application of the study relate to these goals, values, and principles?

6.1.2 System Boundaries

Definition of System Boundaries

The scope of an LCA describes the boundaries which define the system being studied. Decisions selecting system boundaries and parameters marking the study can have a significant impact on the final outcome of the assessment, and the output it provides. System boundaries definition process should be performed according to the main objective of the study. The system boundaries should be chosen according to the purpose of the study [43]. One of the drawbacks of LCA is its tendency to overlook environmental impacts related to the construction phase. However, a true life cycle always starts with the extraction of the raw materials from the earth and ends with the final disposal of the refusals in the earth. In practice, every system can be described, but if the described system does not satisfy the condition illustrated above, it does not represent an LCA but an eco-balance or an eco-profile.

Decisions on what would be included and what would be excluded would influence data collection processes. A number of detailed studies have reported some norms of cut -off rules, where boundaries should be fixed, so that all bear some levels of subjectivity [44, 45].

System boundaries are also defined as borders between a system and its environment, or between two different systems, and they are defined by resource consumption and emissions to air, water, and solid waste. Because of the extensive use of data in life cycle analysis, and the possibility of not having them all available, a widely common case in developing countries, data can also be collected from the literature, estimations, or mathematical modeling (Fig. 2).

Kirk et al. [35] have pointed out the influence of system boundaries on LCA results, since setting system boundaries in different ways can tip the scales in favor of one technology over another. They showed how the concepts of system boundaries and parameters help illuminate why wastewater decisions may only move problems in time and space, rather than solve them. It is also recommended to draw a process tree (or flow diagram) when establishing boundaries since it gives a better overview of the system [41, 56].

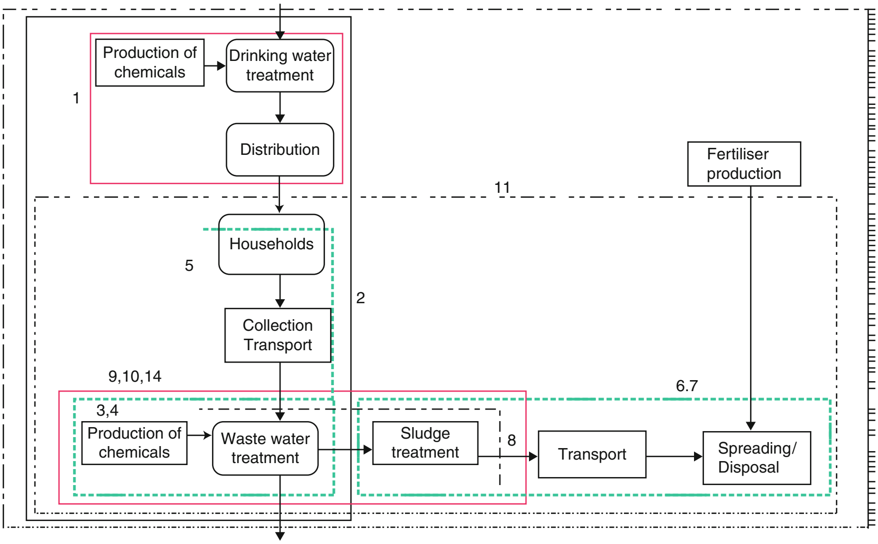

Fig. 2 A simplified sketch of wastewater facility showing different ways of drawing system boundaries assessment of the environmental sustainability of urban water systems, M. Lundin http://www.esa.chalmers.se/publications/PDF-files/Lic/Tep_1999_7.PDF
Source: 1. van Tillburg [46], 2. Crettaz et al. [47], 3. Roeleveld et al. [36], 4. Emmerson et al. [37], 5. Ashley et al. [48], 6. Matsuhashi et al. [49], 7. Neumayr et al. [50], 8. Mels et al. [22], 9. Ødegaard [51], 10. Dennison et al. [52], 11. Dalemo et al. [53], 12. Tillman et al. [39], 13. Bengtsson et al. [54] and Paper I, 14. Grabski et al. [55]

6.1.3 System Function and Functional Unit

The functional unit is a measure of the performance of the product system. The primary purpose of the functional unit is to provide a reference to which the inputs and outputs are related and is necessary to ensure comparability of results.

The function is related directly to the questions that the study is designed to answer, and the functional unit must be selected as the basis for the study. One of the primary purposes for a functional unit is to provide a reference for the system inputs and outputs. A well-defined functional unit that assures equivalence also allows for more meaningful comparisons between alternative systems. In their study of life cycle assessment of wastewater treatment technologies treating petroleum process waters, Vlasopoulos et al. [57] have considered a process water flow of 10,000 m^3/day for a time period of 15 years (system design life) as the function unit used in order to compare the different wastewater treatment processes.

6.1.4 Inventory Analysis

The inventory analysis is a technical process of collecting data, in order to quantify the inputs and outputs of the system, as defined in the scope. Energy and raw

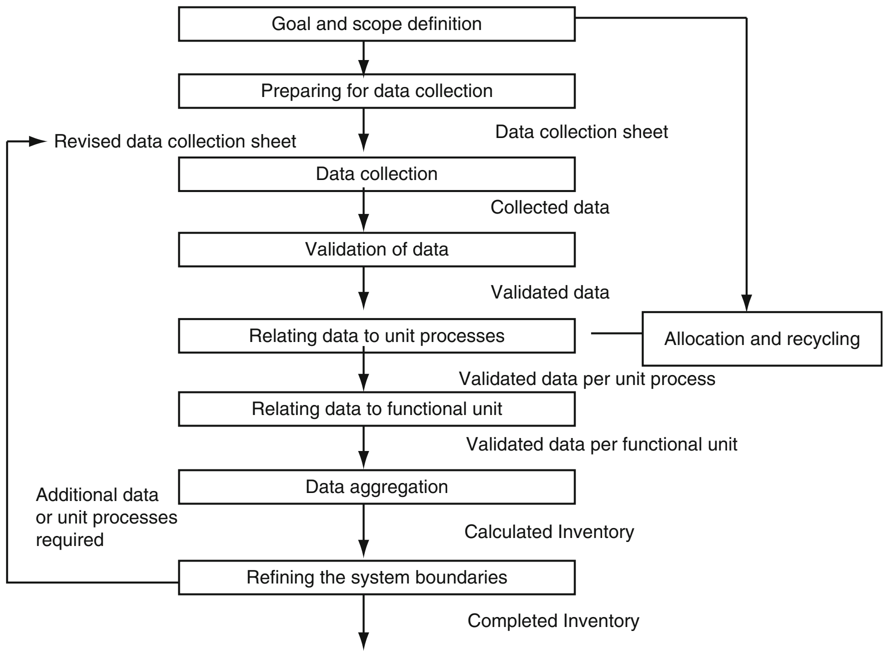

Fig. 3 Inventory analysis diagram
Source: ISO 14041

materials consumed, emissions to air, water, soil, and solid waste produced by the system are calculated for the entire life cycle of the product or service. In order to make this analysis easier, the system under study is split up into several subsystems or processes and the data obtained is grouped in different categories in a LCI table. Conducting an LCA is an iterative process. Figure 3 demonstrates the main steps in producing LCA inventory.

For each step all process input and process output are identified and quantified. All the input and output information obtained should be related to the functional unit. The inventory list is the prerequisite background for the next step, LCIA.

With system boundaries defining the extent, in space and time, of the system being evaluated, parameters of the inventory analysis define the effects that are being monitored. Hence, system boundary defines the actor, and parameters of the inventory stage define the actions evaluated.

6.1.5 Impact Assessment

Life Cycle Impact Assessment (LCIA), also called the evaluation (or valuation) is a process to identify and characterize the potential effects that the system has caused to environment.

In the LCIA, the potential environmental impacts of the environmental interventions generated by the product system are assessed.

The starting point for LCIA is the information obtained in the inventory stage, so the quality of the data obtained is a key issue for this assessment. LCIA is considered to consist of four steps that are briefly described below.

The first step is *Classification*, in which the data originated in the inventory analysis are grouped in different categories, according to the environmental impacts they are expected to contribute.

6.1.6 Category Definition

This is the stage where inventory input and output dates are grouped together into a number of impact categories. For each impact category, emissions that contribute to the same impact are listed. Impact categories may vary depending on the study subject, and the choice of the study impact categories could be made in the early stage of goal definition. Lindfors et al. [44] suggested a number of issues to be taken into consideration when choosing environmental impact categories. These issues include:

- Completeness (all relevant environmental issues should be covered)
- Practicality (it is not very practical to have too many categories)
- Independence (mutually independent categories should be selected to avoid double communing of impacts; e.g., nitrogen oxides contributing to both acidification and nitrification)
- Relation to the characterization step (for the categories selected there should be characterization models available for the next step of the impact assessment)

The most important impact categories used in the literature are:

Climate change
Acidification
Eutrophication
Photochemical smog
Fossil fuel depletion
Eco-toxicity
Ozone depletion
Human toxicity

The second step is called *Characterization*, in which environmental impacts of different emissions and resources consumed are quantified. Quantifying various impacts is usually performed using “equivalence factors” where the potential impact is weighed against the potential impact of a reference substance. Some of the environmental impacts do not have a well recognized equivalence factors, while for some other impact categories the equivalence factors are still controversial with regard to the methodology by which they are derived and with regard to the actual calculations

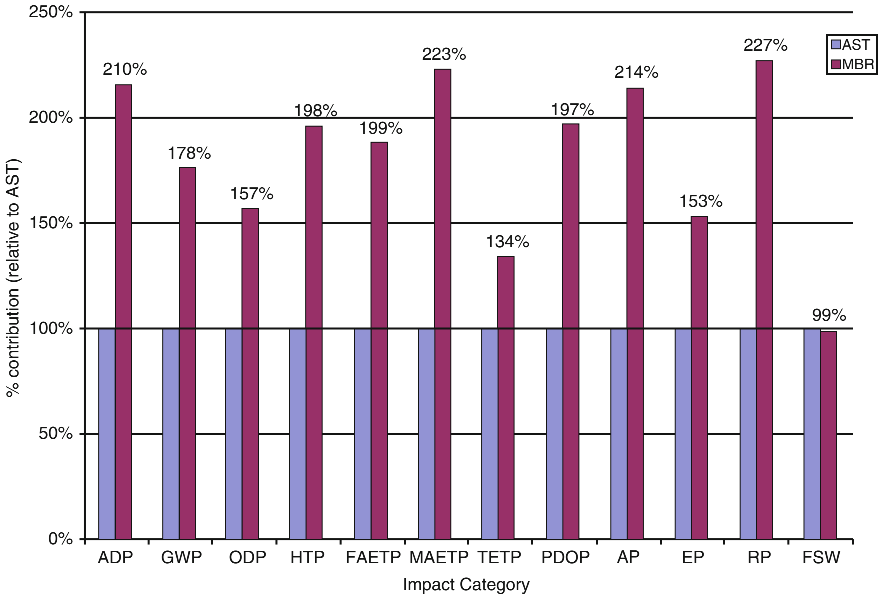

Fig. 4 Percentual comparison of the contribution to the categories for various alternatives of wastewater treatment (after [58])

Some equivalence factors

Environmental impact	Equivalence factor
Global warm up	CO_2 equivalent
Ozone depletion	CFC-11 equivalent
Eutrophication	Phosphate equivalent
Photochemical smog creation	Ethylene equivalent

The result of the characterization step is a list of potential environmental impacts associated with the studied system, also called "environmental profile." The environmental profile of any study is the impact that study would cause, defined in environmental impact categories as related to the function unit selected in the early phases of the study (Fig. 4).

6.1.7 Normalization

Environmental profiles are probably difficult to derive some solid results from. The reason for this is that the scale and units used for each impact category are different due to the different equivalences used in the calculation processes. In order to make the environmental profile more meaningful, they are related to the magnitude of the problem in a given period of time; for example, relating SOx emissions to a country's total SOx emissions hence producing a reference framework.

The formula used in this process is as follows:

$$\text{Normalized effect (year)} = \frac{\text{Effect score}}{\text{Annual contribution of that effect in a certain community}}$$

6.1.8 Valuation

In this process, further aggregation of the data is performed, and various impact categories are weighed so that they could be compared among themselves. The aim is to produce one single score by weighing and aggregating all the scores for the impact categories defined in the study. In this respect, results for the different impact categories are converted into scores, by using numerical factors based on values. This is the most subjective stage of an LCA and is based on value judgments and is not scientific. For instance, a panel of experts or public could be formed to weigh the impact categories. The advantage of this stage is that different criteria (impact categories) are converted to a numerical score of environmental impact, thus making it easier to make decisions.

6.1.9 Interpretation

This is the last stage of the LCA, where the results obtained are presented in a synthetic way, presenting the critical sources of impact and the options to reduce these impacts. The aim is to reduce the amount of qualitative and quantitative information collected throughout the study to a limited number of key issues that could be used in decision-making process. Interpretation involves a review of all the stages in the LCA process, in order to check the consistency of the assumptions and the data quality, in relation to the goal and scope of the study. The three principal steps of the interpretation according to the ISO 14043 standard are identification of the significant issues based on the inventory and the impact assessment phases of the LCA, evaluation of completeness, sensitivity, and consistency checks and conclusions, recommendations, and reporting.

6.1.10 Life Cycle Impact Assessment Methodology

A number of approaches have been put forward and implemented by a number of scholars, of various international entities to reflect the ultimate impacts of the product, or service under consideration. The following are among the most widely used and renowned:

- CML Indicators, introduced by Center of Environmental Studies, Lieden University, The Netherlands, and embracing the following parameters as core parameters for impact assessment
- Abiotic depletion
- Global warming (GWP100)
- Ozone layer depletion (ODP)
- Human toxicity
- Aquatic toxicity fresh water
- Aquatic toxicity sea water
- Terrestrial toxicity
- Photochemical oxidation
- Acidification
- Eutrophication
- Eco-Indicator 99, developed by the PRé Consultants, The Netherlands, with the following damage (end points) categories:
  - Damage to Human Health
  - Damage to Ecosystem Quality
  - Damage to Resources

To determine impacts, inventory results were linked with these damage categories, using damage model. For human damage, Disability Adjusted Life Years (DALY) was the used indicator (Fig. 5).

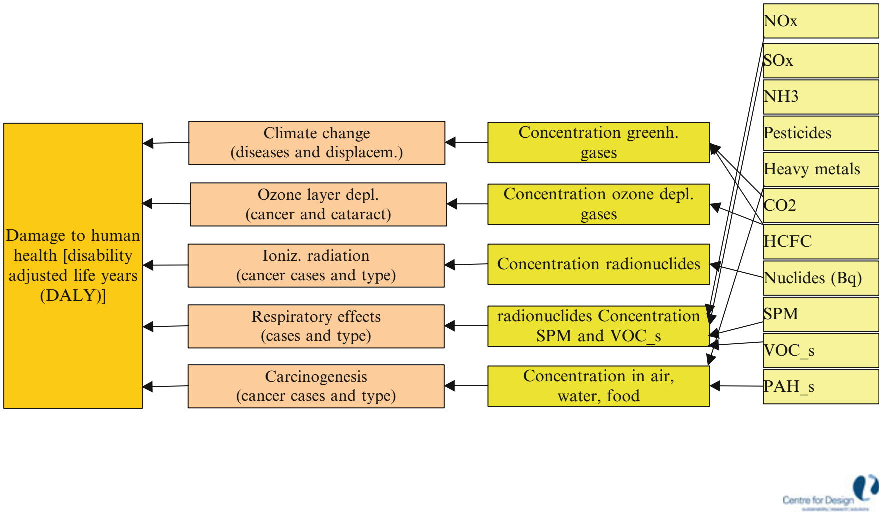

Fig. 5 Human health damage model
Source: Goedkoop M and Spriensma R (1999) The eco-indicator 99 a damage oriented method for Life Cycle Impact Assessment Methodology Report. Amersfoort, the Netherlands, PRé Consultants

- LIME (Life-cycle Impact assessment Method based on Endpoint modeling), Lime methodology, developed by a group of Japanese scientists is using a set of endpoints comprises of:
- Human health
- Social welfare
- Biodiversity
- Plant production

Impact models used in LIME are made of:

- Global warming
- Ozone layer depletion
- Acidification
- Eutrophication
- Photochemical oxidant creation
- Urban air pollution
- Human toxicity
- Eco-toxicity
- Land use
- Resource consumption
- Waste

Ecological Footprint

Footprinting approach, developed by Wackernagel and Rees [6], is based on the idea that one can assess sustainability in terms of relating human consumption of environmental resources (demand) to the carrying capacity of ecological systems (supply). This tool was developed to measure whether a given country or region was using resources at a rate faster than nature can regenerate them. It is a tool that gauges how much of earth we possess and how much we use. More specifically, the EF measures how much biologically productive land and water area is required to produce all the resources a given population consumes and absorb the waste that is produced. By looking at human consumption and comparing it to nature's productivity, the EF provides a means of estimating the impact individuals, organizations, cities, regions, or nations have on nature. It is an attempt to measure the impact of human development on the planet and on future generations.

Water Footprint

The water footprint has been developed in analogy to the ecological footprint concept. Chapagain and Hoekstra [59] described the new concept of water footprint, which is closely linked to the virtual water concept. Virtual water is defined as the volume of water required to produce a commodity or service. The concept was introduced by Allan in the early 1990s [60, 61] when studying the option of importing virtual water (as opposed to real water) as a partial solution to problems of water scarcity in the Middle East. Allan elaborated on the idea of using virtual water import (coming along with food imports) as a tool to release the pressure on the scarcely available domestic water resources. Virtual water import thus becomes an alternative water source, next to endogenous water sources. Imported virtual water has therefore also been called “exogenous water” [62].

When assessing the water footprint of a nation, it is essential to quantify the flows of virtual water leaving and entering the country. If one takes the use of domestic water resources as a starting point for the assessment of a nation’s water footprint, one should subtract the virtual water flows that leave the country and add the virtual water flows that enter the country.

7 Limitation of LCA in Wastewater

The application of LCA in wastewater has made some significant contribution in the state of the art, unveiling a number of previously unknown environmental impacts. Nevertheless, LCA has some inherent limitations that impose on the final package of information produced. On the one hand, economics are hardly included in LCA, leaving a significant voidance of imperative information. Information relevant to hygienic factors such as bacteria, viruses, and others are lacking. Risk issues (accidents + uncertainty) are poorly handled as well as land use and visual impact.

8 Benefits and Limitations of the Life Cycle Approach

Life Cycle Assessment is an inclusive tool. All necessary inputs and emissions in many stages and operations of the life cycle are considered to be within the system boundaries. This includes not only inputs and emissions for production, distribution, use and disposal, but also indirect inputs and emissions – such as from the initial production of the energy used – regardless of when or where they occur. If real environmental improvements are to be made by changes in the product or service, it is important not to cause greater environmental deteriorations at another time or place in the Life Cycle.

LCA offers the prospect of mapping the energy and material flows as well as the resources, solid wastes, and emissions of the total system; i.e., it provides a “system map” that sets the stage for a holistic approach. The power of LCA is that it expands the debate on environmental concerns beyond a single issue, and attempts to address a broad range of environmental issues, by using a quantitative methodology, thus providing an objective basis for decision making. Unfortunately, LCA is not able to assess the actual environmental effects of the system. The ISO 14042 standard, dealing with LCIA, specially cautions that LCA does not predict actual impacts or assess safety, risks, or whether thresholds are exceeded. The actual environmental effects of emissions will depend on when, where, and how they are released into the environment, and other assessment tools must be utilized. For example, an aggregated emission released in one event from one source, will have a very different effect than releasing it continuously over years from many diffuse sources. Clearly no single tool can do everything, so a combination of complementary tools is needed for overall environmental management.

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Overview of Wastewater Management Practices in the Mediterranean Region

O.R. Zimmo and N. Imseih

Abstract The INNOVA-MED Coordination Action is an integrated group of 8 EC funded projects dealing with wastewater treatment and water management. Deliverable D.14 (this report) is under Workpackage 5, which is concerned with the "Integrated Management of Wastewaters in the Mediterranean Area." This workpackage deals with different aspects of wastewater management and water resources management through assessing the technical, financial, socio-economic, institutional, and regulatory influences on integrated wastewater management. Expert group 5 was set up to provide an exchange of experience of project partners and contributing stakeholders, with the focus on:

- Decentralized management of wastewater treatment and reuse for small communities.
- Identification of the national/sub-national water management policies which perpetuate current practices and broaden the existing studies on local capacity to recover costs to encompass both small, medium, and large sized municipalities.

This will ultimately lead to the formulation of suggested policies which may set the stage for the decentralization of authority, local participation, and infrastructural and capacity development.

This report (D14.Report of Expert Group 5) provides a final overview of management practices and recommendations based on national/sub-national policy. It will provide an identification of weakness in wastewater distribution, and further research needed.

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1 Background

In the Mediterranean region, water resources are limited and unevenly distributed over space and time. There are similar environmental and development issues, specifically in water resources management and development and pollution control, throughout the region. The improvement of water supply and the efficient use of wastewater in the Mediterranean countries will allow advancement for social, economic, and political stability in the region, considering that the Mediterranean countries are among the regions of water stress in the world.

The Mediterranean climate is characterized by hot and dry summers and mild winters, in which the major part of the annual precipitation is received. Rainfall is non-uniformly distributed over the region; therefore; there is a great difference on the two shores of the Mediterranean basin (North/East and South) and each is facing different environmental problems. The low and uneven distribution of rainfall is the main reason for the scarcity and irregular availability of the internal freshwater resources of the majority of countries in the Region.

Droughts are another problem seriously affecting freshwater availability. Drought is defined as a substantial decrease below long-term average rainfall, and it is difficult to forecast. According to the Blue Plan [21], renewable water resources are very unequally shared across the Mediterranean basin with around 72% located in the North (Spain, France and Monaco, Italy, Malta, Bosnia-Herzegovina, Croatia, Slovenia, R.F. of Yugoslavia, Albania, and Greece), 23% in the East (Turkey, Cyprus, Syria, Lebanon, Israel, Palestinian Territories of Gaza and the West Bank, and Jordan), and 5% in the South (Egypt, Libya, Tunisia, Algeria, and Morocco). Available water resources are becoming increasingly scarce, are threatened by over-exploitation, and are becoming increasingly vulnerable to different pollution sources.

The countries in the Southern Mediterranean and Middle East region are also facing severe water shortages. Some countries have few naturally available fresh water resources and in most cases surface water is being utilized to their maximum capacity. These countries thus mainly rely on groundwater, which has often led to the over-exploitation of groundwater aquifers. This has resulted in sea and brackish water intrusion in many coastal areas. Some countries have reverted to tapping into fossil aquifers or non-renewable water, such as the intensive exploitation of non-renewable resources of Saharan aquifers in Libya, Egypt, Tunisia, and Algeria.

Problems of water scarcity will increase because of population growth, rise in standard of living, and urbanization, in which these factors will lead to both an increase in water consumption and pollution of water resources. Most Mediterranean countries rely mainly on agriculture, tourism, industry and other economic activities for their economic and social development. Irrigated agriculture, which is in strong 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. Therefore, policy makers are feeling the need to develop additional water resources as well as to preserve the existing ones. Reclaiming and recycling water is becoming an important component of the national resources policy since it is designed to encourage integrated and efficient management and use of water resources.

The main objective of the INNOVA-MED project is to explore the interaction between the different components of the research carried out within different programs and countries, to coordinate the research activities of ongoing EU and national projects dealing with development of innovative technologies for wastewater treatment and treatment and disposal of sludges and with application of innovative practices for re-use of reclaimed water and to facilitate the communication with researchers and national and regional institutions from the MPC and allow a broad dissemination and transfer of the knowledge/technology/practice to the Mediterranean area.

Workpackage 5 deals with the Integrated management of wastewaters in the Mediterranean area. Its main objectives are to exchange knowledge and experiences gathered at the European, national, and regional level in MPC related with the sustainable wastewater management; to evaluate the current water distribution practices in the MPC (extent of sub-national vs. local authority, identification of sub-national vs. local responsibilities); to identify weaknesses of current wastewater management conditions (financial and technical indicators, affordability, willingness to pay); to produce reliable recommendations (Amending current practices, alleviating identified weaknesses); and to strengthening long-term regional cooperation and sustainable development in the MPC.

This deliverable (D14) is an output of Expert Work Group 5 and belongs to workpackage 5. It will provide a final overview of management practices and recommendations based on national/sub-national policy. It will provide an identification of weakness in water distribution, and further research needed.

2 Overview of Wastewater Management Practices in Mediterranean Countries

The provision of appropriate means of water supply and sanitation has long been considered a basic human right. Water supplied through piped networks is intermittent in many countries of the Eastern Mediterranean region, such as Jordan, Yemen, Lebanon, and Syria. In some cases, people have to wait for several days or weeks for their turn, so they use private vendors to fulfill their water needs. The high percentage of unaccounted-for-water is another serious problem facing piped water supply systems in most countries. This has been estimated to range from 30 to 40% in countries like Morroco, Lebanon.

Sanitation services have been given less priority than water supply since the provision of water is considered more urgent. Untreated wastewater usually contains pathogenic microorganisms and toxic compounds that can cause various diseases, as well as nutrients (mainly nitrogen and phosphorus) that can stimulate the growth of aquatic plants. Historically, wastewater collected from communities was discharged to receiving water, such as rivers, lakes, and oceans, or land. Yet the progressively increasing population, mainly in urban areas, has led to a serious deterioration of water and land resources and as a result effluent discharge standards were developed and are being adopted.

Proper wastewater management is now being increasingly required in the Mediterranean countries to ensure a sustainable environment through protecting public health, maintaining aquatic ecosystems, and improving and protecting water resources. Most countries in the Region are classified as being semi-arid with dry ecosystems. Average annual rainfall is so low that irrigation is necessary in the majority of countries of the Region. As previously mentioned, freshwater availability is low so this makes water scarcity a significant challenge currently facing the Region. Therefore, the reuse of wastewater is now being considered a resource rather than a waste. The perception of wastewater management in most countries has generally shifted from its conventional objectives of health and environmental protection, to be considered as a valuable resource where treated effluents are utilized to increase national water resources.

In the Mediterranean Region, a relatively large number of people lack access to improved water supplies and there are even more without improved sanitation facilities. Generally, priority has been given to the provision of water supplies over sanitation. The situation is relatively harder in the rural areas compared with the urban ones. Thus, a major obstacle preventing wastewater reuse is the lack of such sanitation provisions. The weaknesses in current wastewater management practices in Mediterranean countries is further discussed below.

2.1 Weaknesses in Current Wastewater Management Practices

Overall sewerage coverage is modest in most countries of the Region due to the high costs involved. In general, governments in the developing countries of the Mediterranean basin have not been encouraged to promote sanitation projects because it is presumed that huge investments are required. This is mainly due to the fact that most planners, engineers and decision-makers consider conventional sanitary sewers as the best way to collect wastewater. This has therefore slowed the development of sanitation services. This is especially apparent in urban areas where population increase and density are normally higher than in the rural ones.

The most commonly used methods for wastewater disposal, mainly in rural areas are small boreholes, simple pits, cesspits, septic tanks, and ventilated improved pit latrines. Cesspools, which are usually poorly managed in most cases, are the most common alternative for wastewater disposal. Yet they have created a strong concern since seepage from cesspools has contaminated scarce freshwater resources and created several negative health and environmental impacts. Also, the opportunity to reuse the wastewater is a lost since it is disposed and buried away in these pits. When compared with agricultural water consumption in the region, water reuse quantities constitute very small percentages.

Jordan

Jordan has a relatively high rate in sewerage connections (a nationwide average of approximately 50%) and this is reflected in the amount of wastewater collected. There were nineteen wastewater treatment plants in full operation in 2001. The total wastewater flowing into these plants was estimated at 88.637 million cubic meters during 2001.The effluent quality of the nineteen plants varied greatly depending upon, among other factors, the method of treatment utilized. Eleven plants fulfilled the local regulatory effluent quality requirements as specified in the Jordan Standard 893/1995 (JS: 893/95) for discharge to wadis. Sixteen plants satisfied the reuse requirements in this Jordan Standard while all plants provided effluent quality in full compliance with reuse requirements for irrigating fodder crops.

There are plans in Jordan to upgrade overloaded wastewater treatment plants and to build new ones to expand wastewater management provisions, particularly in rural areas. It is expected that by the year 2010, the quantity of treated wastewater will be about 220 million cubic meters per year. Effluents from most wastewater treatment plants in Jordan have been utilized for irrigation purposes. This has been necessary in order to increase the scarce water resources of the country [1].

Morocco

The amount of wastewater collected varies greatly in Morocco depending upon the rate of connection to the sewerage network. The rate of connection was the highest at 45–77% in small urban centers in the year 2000. These rates did not improve proportionally to the increase in population growth over the 1994–2000 period as only 1.2 million people were connected to the sewerage network compared with a population increase of two million.

At present, some 39% of the rural population has access to improved sanitation means. In the rural areas 90% of the onsite systems are cesspools and the remaining 10% are septic tanks. Lack of piped water supplies, local habits and poverty have all been cited as major obstacles hindering the provision of improved sanitation facilities for the rural populations [1].

Egypt

In 1996, the urban areas of Cairo had the highest sewerage coverage at 78.8% compared to only about 6.9% in the urban areas of the Red Sea and north Sinai. The overall average sewerage coverage for all urban areas of Egypt is 53.8%. In the rural areas the average is 9.1%, ranging from 0.5 to 38.8%.

In the areas which are not connected to the sewerage network, various onsite methods for wastewater disposal are used, such as cesspits. Some dispose of their raw sewage into adjacent drains and canals. In densely populated areas, the delta area for instance, such practices have created a grave state of affairs.

Onsite units are used by 36 million people (about 60% of the total population). A small number of this population utilizes septic tanks with unlined bottoms, while the majority rely on seepage pits. Overflowing onsite systems are a common phenomenon that has been the source of surface wastewater ponding conditions and contamination of surface water used for irrigation [1].

3 Water Recycling and Reuse in the Mediterranean Region

3.1 Overview of Wastewater Reuse in Mediterranean Countries

The importance of water reuse may be studied through the comparison of water reuse potential with total water use. Water recycling and reuse is generally small compared to total water use but it is expected to increase significantly. It is and will become more significant in the water scarce regions of the Mediterranean Basin.

In most of the countries in the Mediterranean region, wastewater is being reused at different extents within planned or unplanned systems. In many cases, raw or insufficiently treated wastewater is applied. In other cases, wastewater treatment plants are often not functioning or overloaded and thus discharge effluents not suitable for reuse applications. This leads to the existence of health risks and environment impacts and to the occurrence of water-related diseases.

In situations where conditions for reuse are met, treated effluents are being reused for different purposes without presenting any risk for human health. In these cases, recycled water is an important alternative resource for sustainable development and food production. Only a few Mediterranean countries have incorporated water reuse in their water resources planning and have official policies calling for water reuse, these include Cyprus, Israel, Jordan, Egypt, and Tunisia.

In Tunisia, recycled water accounted for 4.3% of available water resources in the year 1996, and may reach 11% in the year 2030. In Israel, it accounted for 15% of available water resources in the year 2000, and may reach 20% in the year 2010. The volume of treated wastewater compared to the irrigation water resources is actually about 7% in Tunisia, 8% in Jordan, 24% in Israel, and 32% in Kuwait. Approximately 10% of the treated effluent is being reused in Kuwait, 20–30% in Tunisia, 85% in Jordan, and 92% in Israel [2].

In Mediterranean Regions, where touristic structuring and investments are concentrated, treatment plant effluents have started to be used for irrigation. In residential areas, these effluents are used for garden and park irrigation, while in other places wastewater is collected in stabilization tanks and is used for agricultural purposes.

Wastewater has been used in the Mediterranean basin as a source of irrigation for centuries. In addition to providing a low cost water source, the use of treated wastewater for irrigation in agriculture combines three advantages: (1) the fertilizing properties of the wastewater eliminates part of the demand for synthetic fertilizers and contributes to decrease levels of nutrients in receiving waters and land; (2) wastewater reuse increases the available agricultural water; and (3) it may eliminate the need for expensive tertiary treatment.

The need to increase water resources in finding alternative sources, as well as economic and environmental issues are the main driving forces for water reuse development in the Mediterranean region. Water resources in the Mediterranean region are currently scarce and threatened by pollution. This largely affects development of water reuse. The cost effectiveness for the use of recycled water and environmental issues, such as the gradually increasing stringent water quality discharge regulations, are also playing a significant role in this regard.

The main benefits of wastewater reuse are:

- Increased amounts of water for irrigation
- Injection to groundwater for feeding
- Reuse in Double Distribution Systems
- Formation of recreational areas
- Others (construction, prevention of salt-water intrusion)

The purpose of water reuse and recycling is to attempt to close the gap in the water cycle and allow sustainable use of the available fresh water resources. Water reuse may be considered as an essential part of the environmental pollution control and water management strategy of any nation if an integrated approach is take in water resources management. Recycled water may be considered a valuable resource since it provides significant additional renewable, reliable amounts of water and contributes to the conservation of fresh water resources. It may be considered as an essential source of water and nutrients in agriculture schemes and can eventual lead to reducing chemical fertilizers' utilization and to increasing agricultural productivity.

With proper management, the reuse of recycled wastewater can reduce pollution of water resources and sensitive receiving bodies. It may also contribute to desertification control and desert recycling. Saline water intrusion may be controlled in coastal aquifers through groundwater recharge operations. Other social and economic benefits may result from such schemes such as employment and products for export markets. Yet it is of great importance that the development of reuse prevents negative effects on environment and public health since wastewater content in mineral and organic trace substances and pathogens represents a risk for human health. Therefore, adequate treatment is an essential pre-requisite which must be provided for the intended reuse.

Some drawbacks to reuse of wastewater in the Mediterranean must also be mentioned. Water reuse may be seasonal in nature, in that during the wet season, an overloading of treatment and disposal facilities may occur, leading to seasonal discharge of raw wastewaters. Health problems, such as water-borne diseases and skin irritations, may occur if people come into direct contact with reused wastewater.

In many cases of the Mediterranean countries, reuse of wastewater is not economically feasible because of the requirement for an additional distribution system. The reuse of reclaimed wastewater is not culturally or religiously accepted in a large number of these countries. These circumstances have been major considerations for national authorities and have thus become limitations to the implementation of a reuse orientated systems.

Palestine

About 65% of the West Bank population is not served with sewerage networks, and uses mainly cesspits and occasionally septic tanks. The other 35% is served with sewerage networks, but less than 6% of the total population is served with treatment plants. It was reported that only 10% of the wastewater treatment plants in Palestine meet the effluent criteria of their original designs. In fact, most wastewater treatment plants were described as being environmental hazards.

Inadequate disposal of wastewater pollutes the neighborhoods and groundwater of the West Bank aquifers and poses serious risks to the health and

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environment of Palestinian communities. Current pressure on the environment will be worsening by the expected population growth.

Irrigation with raw wastewater has been practiced in many sites of the West Bank. Crops and vegetables like parsley, mint, peppers, eggplants, squash, cauliflower, radishes, and olive trees are being irrigated with untreated wastewater without any official health control or due consideration to possible health or environmental implications. The only controlled reuse practice is at Birzeit University, where treated effluent is used in the irrigation of the University's garden. Health and agricultural officials see great potential for reuse in agriculture and landscape irrigation, groundwater recharge, aquaculture and in industry, such as stone cutting [3].

Jordan

Jordan is recognized as one of the pioneer countries in the region that utilize their wastewater efficiently. Out of 79.5 million m^3 that was treated at 17 WWTPs in year 1999, about 67 million m^3 was indirectly used for irrigation in different parts of the country. About 52 million m^3 was indirectly used for unrestricted irrigation in the Jordan Valley after blending with freshwater in wadis. About 15 million m^3 was directly used for restricted irrigation indoor and within the surroundings of existing WWTPs.

The total number of farms that are directly irrigated with reclaimed wastewater in a sanctioned manner is about 20, distributed in different parts of the Kingdom. Each farmer signs a contract with the Ministry of Water and Irrigation for irrigation with reclaimed wastewater. According to this contract, land area, irrigated crops, irrigation system, amount of water, and water price are determined.

The total land area of these farms is about 1,405 ha of fodders, fruit trees, and forestry, utilizing 15 million m^3 of reclaimed wastewater. Due to the topography and the concentration of the urban population above the Jordan Valley escarpment, the majority of treated wastewater is discharged into various watercourses and flows downstream to the Jordan Valley. Treated or poorly treated effluents mix with the fresh surface water. Thereafter, blended water is used for unrestricted irrigation utilizing about 52 million m^3 of reclaimed wastewater [4].

Tunisia

In Tunisia, the expected amount of recycled water in the year 2020 is expected to be approximately 18% of the available groundwater resources and could be used to replace groundwater currently used for irrigation in areas where excessive groundwater mining is causing salt water intrusion in coastal aquifers.

Treated effluents are reused in about 35 irrigated districts in Tunisia. Each wastewater treatment is equipped with conveyance and distribution utilities, which include pipelines, pumping stations and regulation reservoirs and all irrigation techniques are employed, including sprinklers. There are, however, certain restrictions are imposed when sprinklers are used, for example, they should be far from public roads, residential areas and water supply reservoirs. Sprinklers are not allowed in arboricultural schemes. An estimated area of 6,603 hectares is equipped for irrigation while the part actually irrigated with treated effluents is about 4,380 hectares from which 1,020 are planted with cereals, 2,060 with fodder crops and 1,300 with arboriculture [1].

Treated wastewater reuse schemes have also been carried out for irrigating golf courses and has been successfully implemented. Aquifer recharge by treated wastewater is still being experimented on by the Ministry of Agriculture, which is conducting studies on its feasibility. Treated effluent reuse for industrial purposes is currently not carried out since demand for such water is minimal. However, with increasing stress being imposed on water resources and subsequent increases in the cost of water, some industries are resorting to using reclaimed water. Future industrial effluent reuse is expected to increase in Tunisia due to regulatory requirements to save water and an incentives policy for such programs.

Turkey

General applications of wastewater reuse in Turkey are irrigation, process water, and recreational areas formation. In Turkey, industrial wastewater reuse is applied as wastewater recovery, where recovered wastewater is that water used in the industrial process. It is especially reused in industrial plants near Istanbul, due to the high water costs.

Due to the rapidly developing tourism especially along the Aegean and Mediterranean Coast, water reuse for other purposes is gaining more importance. Tourist villages are being built as single units for their wastewater management since they are usually far away from municipal service boundaries. Water reuse is also gaining importance in large cities like Istanbul. Newly developed satellite towns within the Istanbul metropolitan area are planned in order to meet a part of the water requirement by use of reclaimed water. An example of this type of development is the Anatepe Satellite town project funded by Emlak Bank of Turkey. The reclaimed wastewater is designed to be used to irrigate parks, for washing cars and fire fighting [5].

Yet, reuse of treated wastewater for irrigation has not been considered consciously till now as the country has not yet experienced severe water

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shortages. In the nearest future, wastewater reuse will be one of the most important environmental issues in Turkey. As an initial step towards effluent use in irrigation, the existing WWTPs must either efficiently operate their disinfection units and/or add such facilities to their treatment systems. Moreover, it is important that the farmers are informed on the safe use of effluents in irrigation and public awareness and training is another important issue that should be considered by the legal local and/or governmental related authorities [6].

Cyprus

In Cyprus, there is a total of 25 wastewater treatment plants currently in operation. Aside from these treatment plants, which serve the big cities some municipalities and rural communities, there are also some smaller WWTPs (about 175) located in hotels, military bases and hospitals. Currently, the needs of 45% of the urban population and 12% of the rural population are covered [7]. Nowadays, Cyprus promotes the construction of new sewerage networks and WWTP, as well as extensions at the already working systems, with reference to achieving harmonization with European Directive 91/271/EC, according to which every area with over 2,000 residents (municipalities and big communities), must have their own WWTP.

Recycled domestic water is presently used for the watering of football fields, parks, hotel gardens, etc. (1.5 million m^3/yr) and for the irrigation of permanent crops in particular (3.5 million m^3/yr). It is estimated that by the year 2012, an amount of approx. 30 million m^3/yr of treated sewage effluent will be available for agriculture and landscape irrigation.

No environmental impacts have been observed by the reuse of wastewater due to the fact that very strict standards have been set.

Egypt

In 2000, available freshwater quantities were estimated at 55.5 billion cubic meters per year, while the total annual demand was 69.7 billion cubic meters with an annual agricultural withdrawal of 47.4 billion cubic meters [1].

Egypt has adopted a policy of wastewater reclamation and reuse in irrigated agricultural land to alleviate the pressure imposed by increasing demands on freshwater resources. Reuse for irrigation has been practiced since 1930 on Al Gabal Al Asfar farm where primary treated wastewater has been used in irrigating an area of 10,000 acres.

Most of the wastewater generated in Egypt, treated or otherwise, flows into agricultural drainage canals. Some of it receives secondary treatment while the rest is either treated to a primary level or untreated. There is no coherent irrigation reuse policy to manage the utilization of this water. Recently, however, the Ministry of Agriculture and Land Reclamation has started an agricultural reform program that includes effluent reuse for woodland forests [1].

4 Status of Wastewater Recycling and Reuse Regulations and Guidelines in Mediterranean Countries

4.1 Wastewater Recycling and Reuse Guidelines in the Mediterranean Region

In the Mediterranean region, wastewater reuse schemes are primarily considered for agricultural and landscape irrigation (as such in Jordan, Palestine, Israel, Turkey, among other Mediterranean countries) and groundwater recharge. Industrial reuse is rarely practiced, although it is gaining importance and is beginning to appear as a feasible fresh water alternative to some industries. To this day, there are no specific Mediterranean guidelines regulating water reuse.

The EU-Mediterranean countries, however, must comply with the European Directive (91/271/EEC), which discusses issues concerning urban wastewater treatment. In article 12, this directive specifies that "treated wastewater shall be reused whenever appropriate" [8].

In order to reduce the environmental and health impacts of wastewater reuse, some Mediterranean countries have adopted several standards and guidelines that differ from each other even at the regional level. Practice of wastewater reuse mainly depends on a country's economy, infrastructural status covering wastewater treatment capacity and capability, educational level, climate, water supply, balance between water requirement and demand, intensity of agricultural activities, population, social habits like cultural and religious prejudice, and many other factors. While most of the developed countries have established low risk guidelines or standards based on a high technology/high-cost approach, many developing countries have adopted an approach based on WHO guidelines that refer to low-cost technologies and focus on health risks. However, the current situation in some developing countries is the direct uses of untreated wastewaters for irrigation without taking into account the stated guidelines and standards, and associated risks [6].

In the following section, the current practices and the potential creation and implementation of wastewater recycling and reuse regulations and/or guidelines in various Mediterranean countries are discussed for selected Mediterranean countries.

4.2 *Current Practices of Wastewater Recycling and Reuse Regulations and/or Guidelines*

Generally, wastewater reuse standards in countries of the Mediterranean Region are either adopted from WHO standards or other international standards without adapting them to suit local conditions [9]. The following Mediterranean countries have created and are currently implementing regulations and/or guidelines for wastewater recycling and reuse and are discussed below.

Available standards are summarized for Egypt, Jordan, Lebanon, Palestine, Greece, Turkey, Tunisia, Cyprus, Spain, and Morroco. No official specific standards are recognized for wastewater reuse in Egypt, Lebanon, or Palestine yet there are generally accepted wastewater reuse guidelines.

4.2.1 Egypt

In Egypt, so far there are no adopted guidelines or codes of practice to regulate reuse activities. Wastewater reuse has been practiced since 1930 in the irrigation of orchards, in sandy soil areas like Al Gabal Al Asfar and Abou Rawash. Yet there are no programs to monitor the quality of reclaimed wastewater, before or after reuse, for possible health risks on farm laborers and end users of products [1]. Serious concerns have been expressed on the reuse of reclaimed wastewater due to possible negative public health and environmental implications. Mainly in rural areas, where improved sanitation coverage is very low, increased concerns have been attributed to the uncontrolled discharge of untreated wastewater into irrigation canals and other water receiving courses.

In 2000, available freshwater quantities in Egypt were estimated at 55.5 billion cubic meters per year, while the total annual demand was 69.7 billion cubic meters with an annual agricultural withdrawal of 47.4 billion cubic meters [1]. In attempts to alleviate the pressure imposed by increasing demands on freshwater resources, Egypt has adopted a policy of wastewater reclamation and reuse in irrigated agricultural land.

There is no coherent irrigation reuse policy to manage the utilization of treated wastewater however, the Ministry of Agriculture and Land Reclamation recently started an agricultural reform program that includes effluent reuse for woodland forests. About 1,000 acres of forests have been irrigated with reclaimed water in Luxor, Qena, New Valley, Edfu, Ismailia, Sadat City and South Sinai.

There are many decrees in Egypt concerning the quality of wastewater effluent. These include the national regulation – Decree No. (44)/2000–Amendment to Executive Bulletin of Law No. 93/1962 concerning discharge of liquid wastes. It was issued by the Ministry of Housing, Utilities and Building Societies in 2000, and provides quality standards for liquid wastes. Yet no specific standards exist for wastewater reuse.

Effluent reuse for industrial purposes is minimal because many industrialists have concerns about negative impacts treated wastewater might have on machinery. Nonetheless, industries have been prompted to treat and reuse their effluents whenever possible through the enforcement of Environmental Law 4/1994.

The extreme rigidity of the conventional water resources in Egypt is forcing planners to consider unconventional water. One of the unconventional resources being integrated into the Egyptian water resources plan is the reuse of reclaimed municipal wastewater. Artificial recharge of groundwater, due to its advantages over the conventional direct application, is being considered as one mean for utilizing this water [10].

Artificial recharge with wastewater can be an added dimension for the reuse policies in Egypt. Law 48/1982 imposes legal constraints on effluent reuse for aquifer recharge purposes but there are several concerns about identifying the lines dividing aquifers of drinking water quality from those of non-potable quality.

The preparatory efforts for artificial recharge with wastewater application in Egypt are carried out in two parallel channels; a framework for the application of artificial recharge with wastewater and laboratory experiments to study the processes that take place during the infiltration of treated waste water as a preliminary step in producing guidelines for its optimization. A framework for the introduction of AR/WW in Egypt was prepared. The framework included possible locations, amounts of available wastewater for these locations, general environment and health safety considerations, recharge method, and range of applications.

Below are the Egyptian laws and regulations related to wastewater reuse [25]

- Law 93/1962: This law is concerned with wastewater disposal, in which it regulates the authority of the Ministry of Housing to construct public sewage systems and to prohibit or permit the discharge of fluid wastes into public sewers and/or on surface lands. According to amendments to the standards of law 93/1962, wastewater that is treated by primary treatment may be used in cultivating timber trees only. Wastewater that is treated by secondary treatment may be used in the cultivation of palm trees, cotton flax, jute, cereal, forage crops, field crops and nut fruits, flower nurseries, and thermally processed vegetables and fruits. According to these standards, only the tertiary treated effluent can be used for cultivation of uncooked eaten plants and vegetables, as the water in this advanced type of treatment is free from all types of pathogens.
- Decree 649/1962 and Decree 9/1989: These decrees set the conditions and criteria set for wastewater disposal on surface areas distinguished between sandy soils and clay silt soils.
- Minister of Housing Decree No. 44/2000: Minister of Housing Decree No. 44/2000: This decree concerns the new executive regulation for law No 93/1962. According to Article 15 of this regulation, wastewater use in agriculture must meet a defined set of criteria.
- Law 48/1982: Law 48 concerns the protection of the Nile and its waterways against pollution. Decree 8/1983 by the Minister of Irrigation is the executive regulations of the Law. Law 48 prohibits discharges to the Nile, canals, drains

and groundwater without a license issued by the Ministry of Public Works and Water Resources.

- Law No 12/1984: This law names the Ministry of Water Resources and Irrigation as the guardian of all water resources. It also regulates the authority of the Ministry to allocate irrigation water and to construct drainage systems. According to this law, the drainage of waters to public canals cannot be done without the Ministry's permission.

In Egypt, no guidelines have yet been adopted but the 1984 martial law regulation prohibits the use of effluent for irrigating crops unless treated to the required standards of agricultural drainage water. The irrigation of vegetables eaten raw with treated wastewater, regardless of its quality level, is also forbidden. Crops chosen for cultivation using sewage effluent are those that cannot be contaminated, such as wood trees, palm trees, citrus, pomegranates, castor beans, olives and field crops, such as lupines and beans.

From the institutional standpoint, seven ministries are involved in wastewater treatment and reuse in Egypt, with unclear delineation of responsibilities and limited coordination among them [22]. There is a clear absence of good policies and action plan on wastewater management as well as standards that are practically impossible to enforce and which limit the effectiveness of pollution control abatement efforts. Dissemination of information among various organizations and to the public is also limited.

4.2.2 Jordan

Water availability in Jordan is restricted relative to demands, groundwater levels are dropping and industrialization pressures are placing ever increasing demands on water resources and the environment. Jordan has asserted a goal of 100% reuse of reclaimed water resources, thereby effectively integrating reclaimed water resources in the national water development strategy [11]. The Jordanian policy is to ensure that wastewater is managed as a valuable resource rather than as a waste. Jordanian policies work to ensure that effluent reuse is practiced without compromising public health.

Effluents from most wastewater treatment plants in Jordan have been utilized for irrigation purposes. There are strict regulations prohibiting the use of raw wastewater for irrigation. Communities without sewers are required to pump out cesspools by private tankers that empty their loadings into prescribed wastewater treatment works. However, lack of organization within the sector means that the control of such practices is sometimes unsatisfactory.

To help maximize the use of reclaimed water, a Water Reuse and Environment Unit has been established within the Water Authority of Jordan, with the responsibility of monitoring and regulating reuse activities. In addition, a National Water Reuse Coordination Committee has been established to provide a forum for discussing reuse issues among key stakeholders. All new wastewater treatment projects are required to include feasibility for effluent reuse.

Jordan was one of the earliest countries to adopt World Health Organization and Food and Agriculture Organization effluent reuse guidelines for irrigation. These were essentially the basis for the Jordanian Standard for treated wastewater discharge and reuse (JS: 893/2002). The national Jordanian standard for wastewater discharge and reuse covers the following items:

- For discharge to streams, storage
- For effluent reuse for agricultural irrigation
- For effluent reuse for agricultural irrigation

The criteria for effluent are largely applied in the implementation of all organized reuse schemes. There are many general provisions in JS: 893/2002 for when reclaimed wastewater may be reused for irrigational purposes [23]:

- When the effluent is used in the irrigation of plenteous trees, irrigation should be halted two weeks prior to harvesting and no fruits should be picked off the ground.
- The use of sprinklers is not allowed except for irrigating golf courses.
- Direct reuse of treated wastewater is not allowed in irrigating vegetables that are eaten raw, such as tomatoes, cucumbers, carrots, lettuces, radishes, peppers, cauliflowers, cabbages, mint, parsley, and coriander.
- It is not permitted to dilute the treated wastewater at the wastewater treatment plants' outlet for the purpose of meeting required regulatory standards.
- The use of treated wastewater is prohibited for aquifer recharge if the latter is utilized for drinking water purposes.
- Several public agencies are vested with primary responsibility for water and wastewater in Jordan such as the Ministry of Water and Irrigation, the Water Authority of Jordan and the Jordan Valley Authority in addition to other governmental and nongovernmental institutions.

Water Reuse Implementation Project (WRIP), which ran through 2002–2004, and The Reuse for Industry, Agriculture and Landscaping (RIAL) Project, funded by the USAID, and implemented by the U.S engineering firm Camp Dresser and McKee (CDM), which commenced in 2004 with the goal of creating successful examples of sustainable, treated wastewater reuse that can be replicated throughout Jordan. These reuse projects aim at working toward sustainable use of reclaimed water resources, providing economic benefit, and supporting community development [11]. The overall goal of the RIAL project is "to implement direct water reuse in Jordan that is reliable, commercially viable, environmentally sustainable, and safe."

4.2.3 Lebanon

In Lebanon, as in many developing countries, nuisance, health conditions, and public pressure brought about an increasing demand for more effective means of wastewater management, particularly in large metropolitan areas along the Mediterranean Sea [12]. Years of civil unrest accompanied with major demographic changes, unplanned development, and inadequate institutional support have hindered Lebanon from developing environmental management and control procedures to comply with its commitments.

There are no formal wastewater reuse schemes implemented. Only two million cubic meters were informally reused for irrigation purposes in 1991. However, unlawful reuse of raw wastewater for irrigation is taking place. The Ministry of Environment has created Decree No. 52/1–Standards for the minimization of pollution to air, water and soil. Ministry of Environment 1996 Standards for urban wastewater minimum levels for treated domestic wastewater, yet no specific standards exist for wastewater reuse.

Considering that water resources in Lebanon are limited, it is necessary that all available water resources be considered as a source for domestic water supply or agricultural use. In the case of aquifer recharge, it is of utmost importance that effluent criteria comprise prescribed minimization of pathogenic and organic contamination with compliance to potable drinking water standards for non-degradable constituents.

4.2.4 Palestine

Due to water scarcity, the reuse of reclaimed wastewater has been taking an increasing interest throughout Palestine. The reuse of reclaimed wastewater in Palestine is a major priority, as confirmed by the Palestinian Water Policy recently adopted by the PWA (Palestinian Water Authority) and the Ministry of Agriculture.

To date, several laws govern water and environmental management in the Palestinian territories. These laws are:

- Safeguarding of Public Water Supplies Ordinance No. 17/1937.
- Water Resources Testing Law No. 2/1938.
- Water Control Law No. 31/1953 in West Bank Governorates.
- Law No. 2/1996 regarding the establishment of the Palestinian Water Authority.

In 2002 the PWA issued the Water Law Number (3/2002). This law aims to develop and manage the water resources, increasing their capacity, improving their quality and preserving and protecting them from pollution and depletion. No specific standards exist for wastewater reuse. According to By Law No. 2 (1996), PWA is responsible for wastewater treatment and reuse. Preparation of policies and strategies for management of wastewater, industrial wastewater, legal and administration are under way.

The reuse of reclaimed wastewater in Palestine is a major priority confirmed in the Palestinian Water Policy adopted by the PWA and the Ministry of Agriculture. Agricultural use of treated effluents was initially intended in Jabaliah and Gaza City. However, implementation failed due to the lack of funds and rejection by local farmers because there is no cultural acceptance. Reuse of treated effluent may become realistic only if effective treatment systems are installed that provide effluents that comply with irrigation standards [3]. Lack of a national strategy and guidelines makes reuse most likely to be rejected. Nevertheless, wastewater in Palestine has a high reuse potential.

4.2.5 Greece

In Greece, water demand has increased tremendously over the past 50 years. Despite adequate precipitation, water imbalance is often experienced, due to temporal and regional variations of the precipitation, the increased water demand during the summer months and the difficulty of transporting water due to the mountainous terrain. In addition, in many south-eastern areas there is severe pressure for water demand, which is exacerbated by especially high demand of water for tourism and irrigation. Therefore, the integration of treated wastewater into water resources management master plans is a very important issue (Angelakis et al. 2002).

In Greece, the problem of water shortage is less acute, compared to other countries such as Palestine and Jordan, and rather local (e.g., mainly in the islands and along the east coast). Several research and pilot projects dealing with wastewater recycling and reuse are currently under way in Greece, in addition to a few small projects on wastewater recycling and reuse which are in practice. Yet no guidelines or criteria for wastewater recycling and reuse have been yet adopted beyond those for discharge (No. E1b/221/65 Health Arrangement Action).

The evaluation of the existing situation in Greece, concerning among others reuse priorities, available treatment plants and effluent characteristics, has led to the formulation of recommendations for developing future guidelines or regulations appropriate to Greek conditions [13]. These recommendations were presented in relation to the different types of reuse, with appropriate specific standards and recommended treatment systems wherever applicable. It was determined that the main type of reuse is related to agricultural activities, while urban reuse has to be considered as a significant alternative, mainly in urban areas of the country. Direct and indirect potable reuse should not be practiced considering the uncertainty of long-term effects, while groundwater recharge for non-potable reuse for creating barriers to salt water intrusion is an interesting alternative.

4.2.6 Turkey

Treated municipal effluent in Turkey is mainly discharged into flowing receiving water bodies like rivers and creeks, and coastal and deep sea environment. Effluent being discharged to rivers and creeks is directly used in agricultural irrigation and/or indirectly used for irrigation purposes, meaning that it is reused through a receiving body. Some constraints in Turkey that are mainly placing restriction on soil, water and energy resources, as well as changes in economic conditions, growing environmental consciousness, and wrong decisions in irrigation system management are negatively affecting the sustainability of irrigation in contemporary agricultural practices [7].

One of the principle laws in the water sector in Turkey is the "The Law of Environment, 1983" [14]. Based on the principle of "polluter pays," this law deals with the issue of environment in a very broad scope. The aim of the law, which considers the environment as a whole, is not only to prevent and eliminate environmental pollution, but also to allow for the management of natural and historical values and land in such a way as to utilize and preserve such richness with concern for future generations as well.

Reuse of wastewater in agriculture is officially not a recent practice in Turkey. As in many other countries in the Mediterranean, indirect (unplanned) irrigational reuse has been applied for many years. The majority of the treated wastewater in Turkey is discharged into seas (62%) making it very difficult for these wastewaters to be reused since most WWTPs that practice sea disposal have only preliminary treatment [15]. It has been reported that some of the wastewater treatment plants in rural areas do not receive raw wastewater since the untreated wastewater is intercepted from the manholes of the sewerage network by the farmer who are in desperate need of irrigation water for their crops. [5]. Traditionally, water reuse is not considered in planning and design of treatment plants in Turkey.

The technical regulations and constraints for irrigational wastewater reuse, issued in 1991 by the Ministry of Environment, officially legitimized water reuse. According to the "Water Pollution Control Regulations," treated wastewater can be used in irrigation. The consumer must obtain a written permission from concerned government organizations. The commission organized by the State Water Organization, İller Bank and Agriculture Ministry and Environmental and Forest Ministry will decide whether the effluent can be used in irrigation or not. The Turkish Water Pollution Control Regulations provide effluent quality criteria for irrigation, which are generally adopted from the WHO guidelines. In addition to the regulations there are other criteria included, regarding the classification of the waters to be used for irrigation [2]. This classification states the maximum allowable heavy metal and toxic elements concentrations as well as the mass limits for application of these pollutants in terms of unit agricultural areas.

4.2.7 Tunisia

In Tunisia, there is growing interest in water conservation and demand management options as a means to cope with the water crisis in the country. Some nonconventional water resources being considered in the country are: desalination, and reclaimed wastewater reuse. The exploitation of non-conventional water resources (the reuse of treated wastewater) is one of ways of the national strategy to mobilize alternative water resources [25]. There is a growing national concern for maximizing the use of reclaimed wastewater.

Wastewater reuse for agriculture has always existed and remains nowadays a widespread practice, sometimes planned and more often not. Wastewater reuse in agriculture has been practiced for several decades in Tunisia, on a seasonal basis, and now it is an integral part of the national water resources strategy. Wastewater is being reused for irrigation of fodder crops (alfalfa, sorghum), cereals, fruit trees (citrus, olives, peaches, pears, apples, grenades, and vineyards), tobacco, cereals, golf courses, green belts, and roadsides [4]. It is important to note that in Tunisia, the farmers pay for the treated wastewater they use to irrigate their fields [2]. In addition to the reuse of treated wastewater for irrigation, it is currently reused for such other purposes as recharge of the aquifers and the protection of biodiversity in wetlands, as in the wetland of Korba, for instance (INNOVA 2009).

A gradual approach to expanding reuse since the mid 1960s has been adopted in Tunisia [16]. 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.

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. Wastewater reuse in agriculture is regulated by the 1975 Water Code (law No. 75-16 of 31 March 1975), by the 1989 Decree No. 89-1047 (28 July 1989), by the Tunisian standard for the use of treated wastewater in agriculture (NT 106- 003 of 18 May 1989), by the list of crops than can be irrigated with treated wastewater (Decision of the Minister of Agriculture of 21 June 1994) and by the list of requirements for agricultural wastewater reuse projects (Decision of 28 September 1995). They prohibit the irrigation of vegetables that might be consumed raw [2]. The reclaimed water quality criteria for agricultural reuse were developed using the FAO guidelines, the WHO guideline [17] for restricted irrigation (<1 helminth egg per liter), and other Tunisian standards related to irrigation or water supply [16].

The 1989 decree states that the responsibility from wastewater collection to use is shared among various ministries: the Ministry of Agriculture, in agreement with the Minister of Environment and Land Use Planning, 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 and the Ministries of Interior, Environment and Land Planning, Agriculture, Economy and Public Health are in charge of the implementation and enforcement of this decree.

4.2.8 Cyprus

The basic sources on water supply in Cyprus are water dams and ground water. Recently, as a result of the water shortage in Cyprus, two new sources of water supply are being developed rapidly, namely, desalination and the wastewater reuse

[18]. In Cyprus, the wastewater generated by the main cities is planned to be collected and used for irrigation. Due to the high transportation cost, the majority of the recycled water will be used for irrigation of hotel gardens, parks, golf courses, etc.

The provisional criteria related to the use of treated wastewater effluent for irrigation purposes in Cyprus, which are in the form of guidelines and Code of Practice for Wastewater Reuse and Sludge Application, are extremely strict guidelines. They are stricter than the WHO guidelines and take the specific conditions of Cyprus into account. These criteria are followed by a code of practice to ensure the best possible application of the effluent for irrigation [2].

In 1995, the sewerage treatment plant of Limassol started its operation and nowadays the entire treated effluent is reused mainly for agriculture and also for gardening purposes in tourist resorts. This project provides a promising alternative source of water which shows that, in the long run, treated effluent can contribute substantially, to the solution of the water shortage in Cyprus [18]. The wastewater reuse system of Limassol, the second largest urban area of Cyprus, provides high quality effluent which is fully recycled and used for many purposes such as groundwater recharge, restricted irrigation such as public amenity areas, golf courses, etc., but excluding vegetable and similar irrigation. In Cyprus, the Urban Wastewater Treatment Directive (91/271/EEC) is under full implementation [19].

4.2.9 Spain

As a result of the implementation of the 1st Wastewater Treatment Plan according to Directive 91/271/CEE, more than 90% wastewater in Spain is already treated. The 2nd Wastewater Treatment Plan will extend treatment to small communities (less than 2,000 inhabitants). Currently, about 5% of the wastewater treated is being reused, and this is expected to increase up to 20% in the forthcoming years.

In Spain, the Government issued ten years ago one Law and one Decree where wastewater reuse was indicated as a possibility, and a minimal statement appeared, indicating the need for an administrative concession and a compulsory report of the Health Authorities. An indication was made that further legal developments would be needed.

There is a bright future for wastewater reuse in Spain, but at present it is compromised, owing to the fact that the projects are appearing and a lot of difficulties arise because of the need for a more complete legal definition. In Spain, there is a strong tendency to decentralize the Administration and give more power to the "Autonomous Governments" [20]. The decisions and permissions for wastewater reuse are given now case per case depending on the Regional Administrations. While there is no national legislation in Spain, at least three autonomous regions (Andalucia, Catalunia and Baleares) have either legal prescriptions or recommendations concerning wastewater recycling and reuse.

A new National Hydrological Plan has been recently published which is favorable to the reuse of treated wastewater for irrigation [2]. In any case, the reuse of treated wastewater is already a reality in several Spanish regions for four main applications: golf course irrigation, agricultural irrigation, groundwater recharge (in particular to stop saltwater intrusion in coastal aquifers), and river flow augmentation. Commercial interest exists and some private water companies invest in Research and Development activities, in collaboration with the Universities.

4.2.10 Morocco

In Morocco, the use of raw wastewaters is a current and old practice. Raw wastewaters are used where they have most value in general. Wastewater reuse practices are mainly carried out in the suburbs of some big cities where agricultural lands are located downstream of effluent discharge, and also in small areas around the treatment networks. Climatic constraints push farmers to irrigate cultivations in places where water resources are available. Wastewater reuse is not a major issue for the management of water resources in Morocco at the moment; however, the situation may be different in a few years due to the increase of the urban population and a rapid increase in drinking water consumption in towns which is expected. This will require the transfer of freshwater resources from one catchment area to another and the replacement of freshwater by wastewater for irrigation.

To date, there are no regulatory standards for treated wastewater reuse in Morocco but reference is usually made to the WHO recommendations. There is, however, a requirement in the 1995 Water Law which affirms the need for reused effluents to comply with the national norm. The irrigation of market garden crops with raw wastewaters is forbidden in Morocco, but this ban is not respected (INNOVA, 2009). This makes the consumer of agricultural products and the farmer face risks of bacteria or parasite disease.

In 1996, the rural engineering department of the Ministry of Agriculture released the draft of limit-values for the evaluation of the quality of irrigation water, which included maximum limits for pertinent physical and chemical parameters in accordance with Food and Agriculture Organization’s guidelines. It also adopted the 1989 World Health Organization’s microbiological guidelines for agricultural reuse. The application Decree (N°2-97-875, dated February 4, 1998) acting as water law 10-95 related to the use of wastewaters stipulates that no wastewater can be used if it has not been beforehand recognized as treated wastewater. The use of raw wastewaters is thus banished.

5 Further Research Required

Generally, wastewater reuse standards in countries of the Region are either adopted from WHO standards or other international standards without adapting them to suit local conditions. It is essential that such adopted guidelines be adapted to prevailing local conditions. Local studies are necessary as they may result in the formulation of guidelines and thus augment the quantities of reclaimed water without compromising and to protect public health. Such studies are essential to ensure effective and safe implementation of wastewater reuse guidelines, as this will increase confidence in reclaimed water as a valuable resource.

Lack of skilled personnel and equipment to conduct preventive and corrective maintenance and the absence of real incentives for employees in the wastewater sector have been generally reported as major obstacles facing the wastewater treatment sector in countries such as Jordan, Palestine, Egypt and Morocco.

The highest priority in the wastewater management sector in the Mediterranean countries which are facing problems can be given to the setting up an effective wastewater management system, which will include: maximization of collection of wastewater; upgrading the existing wastewater collection systems; rehabilitation or upgrading of existing wastewater treatment plants or the construction of new plants; establishment of proper standards for influent and effluent wastewater quality; education of farmers [24].

To assure the public and protect the public health, there is a need to update the scientific basis of the regulations to ensure that the chemical and pathogen criteria are supported by current scientific data and risk assessment methods and to validate the effectiveness of recycled water management practices [2]. 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 [16]:

- 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.

6 Wastewater Reuse Policies and/or Guidelines for Mediterranean Countries

The management of wastewater in the Mediterranean varies from country to country. Any available criteria and their enforcement also differ widely. Some countries have very little or poorly running wastewater treatment facilities and direct reuse of raw wastewater is occurring. This is resulting in serious health hazards and environmental problems. Other countries have a national reuse policy which is being implemented.

Wastewater treatment and reuse criteria differ from one country to another and even within one country. In many countries such as Morocco, Jordan, Egypt, Tunisia, Cyprus, Greece, and Spain, several major projects are already in operation or under planning, where the main reuse projects in the region are related to agricultural and landscape irrigation, and groundwater recharge. Industrial reuse is very rarely practiced.

Due to fundamental differences in the approach with respect to reuse guidelines and regulation, serious difficulties are faced in creating unified policies for the Mediterranean countries. Egypt, Jordan, Tunisia, Palestine, Morocco, and Syria form a group of countries in great need for extensive reuse practices. However, they must be feasible under the social and economical conditions prevailing, which are mainly the shortage of funds, limited experience for both construction and operation of sophisticated treatment systems, inadequate infrastructure including sewers and wastewater treatment plants.

In these countries, strict reuse standards, such as the ones proposed by EPA and/or California, cannot be easily achieved due to their prevailing technological, institutional and, most importantly, economical constraints. The WHO guidelines, which are less strict with the intention to encourage treatment of wastewater prior to crop irrigation, particularly in developing countries, may be more appropriate for these countries until there is an ability to produce higher quality reclaimed water.

The situation is different in countries, including Greece and Cyprus, where there is a higher stage of development. These countries enjoy greater available funds, existing infrastructure and more advanced legislation regarding environmental pollution control. There countries will tend to adopt stricter standards and guidelines than the ones proposed by the WHO.

Therefore, the essential difference in the criteria from one Mediterranean country to the next is partly due to the different approaches undertaken by each country, where some opt for minimizing any risk and have adopted strict effluent reuse criteria, while others is basically a reasonable anticipation of adverse effects resulting in the adoption of a set of water quality criteria based on the WHO guidelines. This has led to substantial differences in the criteria adopted by Mediterranean countries.

In preparing guidelines for municipal water reuse for the Mediterranean Region, some principles must be considered for the variance in different countries. Wastewater quality policies or guidelines should reflect the variances in climate, water flow and wastewater characteristics. They should take into consideration the local conditions of the country, e.g., socio-cultural and environmental factors. They must also be feasible and enforceable.

If unified Mediterranean guidelines are to be adopted, it is expected that they be minimum requirements which should provide the most basic water reuse regulations, so that they may be adopted in every country of the region. For the less developed countries, this will allow them to comply and for the wealthy countries, then they have the choice to opt for higher protection if desired. Due to the high variance in development of wastewater treatment in several countries, all of them cannot be expected to comply with the guidelines in a specified time frame yet these countries must be encouraged to give a commitment to reach the guidelines within a time frame, depending on its current equipment and financial capacities.

7 Conclusions

In the Mediterranean basin, wastewater has been used as a source of irrigation for centuries. In addition to providing a low cost water source, the use of treated wastewater for irrigation in agriculture provides three advantages: First, using the fertilizing properties of the water eliminates part of the demand for synthetic fertilizers and contributes to decrease levels of nutrient in receiving waters (such as rivers, sea, ocean, lakes). Second, the practice increases the available agricultural water. Third, wastewater reuse may eliminate the need for expensive tertiary treatment. However, wastewater is often associated with environmental and health risks. As a consequence, its acceptability to replace other water resources for irrigation is highly dependent on whether the health risks and environmental impacts entailed are acceptable.

Agricultural wastewater reuse is an element of water resources development and management that provides innovative and alternative options for agriculture. The use of reused water for irrigation is mainly due to the scarcity of water resources and inefficient water resource management, both of which are increased by growing population, worsening economic conditions and increasing urbanization.

In the Mediterranean countries, there is a need for a holistic approach with respect to water resources management, and this imposes the need for wastewater reclamation and reuse criteria.

Some countries in the Mediterranean, such as Cyprus, Tunisia, and Turkey, have established national regulation or guidelines, and regional guidelines exist in Spain. Other countries such as Egypt, Greece, Lebanon, and Morocco, are considering guidelines and/or regulations concerning wastewater recycling and reuse. Establishing unified Mediterranean guidelines for municipal water reuse is a challenge because of the lack of comprehensive international guidelines, and of an agreement on the scientific approach that should be adopted to issue such guidelines. Thus, it is expected that providing minimum requirements, which should provide the most basic water reuse regulations, in every country of this region will encourage compliance by all countries and will reduce the threat of water scarcity, allow prosperous food exchanges and develop tourism.

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Reuse of Wastewater in Mediterranean Region, Egyptian Experience

Naglaa Mohamed Loutfy

Abstract Water scarcity in the Mediterranean region is one of the most serious issues. A number of reasons are behind this situation, which include, but are not restricted to, the relatively uneven distribution of precipitation, high temperatures, increased demands for irrigation water, and impacts of tourism. Climate change is expected to aggravate the situation even more. The use of wastewater is one of the most sustainable alternatives to cope with water shortage. It would have a number of advantages that include closing the gap between supply and demand, stopping the pollution of fresh water resources, providing sound solution to water scarcity and climate change, and helping to achieve Millennium Development Goals. With Egypt, trying to cope with water shortage issues, The Ministry of Water Resources, MWRI has developed a National Water Resources Plan, with wastewater reuse as a central mechanism. At present, there are more than 200 wastewater treatment plants in the country. Urban coverage of improved sanitation gradually increased from 45% in 1993 to 56% in 2004. In contrast, rural sanitation coverage remains incredibly low at 4%. The low coverage, in combination with a sub-optimal treatment, results in some problems of water pollution and degradation of health conditions because the majority of villages and rural areas discharge their raw domestic wastewater directly into the waterways. Drainage water reuse is practiced on a very large scale. The official reuse of agricultural drainage water in irrigation amounted to 4.84 km^3/year in 2001. The present aim of the Government of Egypt is to reuse up to 8 km^3/year in new reclamation areas in the near future. Meanwhile, El Salam canal, one of the mega projects in Egypt is transferring a mix of fresh Nile water and wastewater to Sinai, to irrigate thousands of newly reclaimed areas.

Keywords Mediterranean, Wastewater, Egypt, Water scarcity, Climate change, EI-Salam canal

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1 Introduction

Water is one of the most valuable resources on Earth. Water and sanitation have a great effect on human health, food security and quality of life. Demands on water resources for household, commercial, industrial, and agricultural purposes are increasing greatly. Yet water is becoming scarcer globally, with many indication that it will become even more scarce in the future. More than one-third of the world's population – roughly 2.4 billion people – live in water-stressed countries and by 2025 the number is expected to rise to two-thirds [1]. Growing demand for water due to the growing world population is creating significant challenges to both developed and developing countries.

The world populations have grown 1.5 times over the second half of the twentieth century, but the worldwide water usage has been growing at more than three times the population growth. In most countries, human population is growing while water availability is not [2]. World population growth is projected to reach over 8 billion in 2030 and to level off at 9 billion by 2050. The United Nations has challenged the international community to work together to improve the situation, and one of the main objectives of the Millennium Development Goal (MDG) is to halve the number of people without access to safe drinking water and adequate sanitation by 2015.

The Mediterranean region is one of the most populated areas of the globe. About half a billion people live in the Eastern Mediterranean region and population growth rates are among the highest in the world. Increasing urbanization, incomes, and populations are imposing strains on the environment and the finite natural resources, particularly freshwater [3].

According to [43], Mediterranean countries suffer different levels of water scarcity, and water availability is declining to a crisis level especially in the Middle East and North Africa region (MENA).The present imbalanced water demand versus supply is due mainly to the relatively uneven distribution of precipitation, high temperatures, increased demands for irrigation water and impacts of tourism.. The annual rainfall in much of the southern Mediterranean countries including Egypt ranges between 0 and 340 mm. With high potential evaporation, the rainfall is generally insufficient to meet the water demand of crops. Sharp variations between years and among different seasons within a year exacerbate the situation [4]. Moreover, rapid development and industrialization in the area, besides increasing population growth are seriously affecting water resources, posing an extra burden on the already limited stocks.

Another major challenge that is aggravating water scarcity in most of the region, as well as impacting human health and ecological systems, is the continuous deterioration in the quality of the limited surface and groundwater resources because of industrial, domestic, and agricultural effluent discharges. Furthermore, groundwater resources are being over-exploited to meet the ever-increasing domestic, agricultural, and industrial sectors' water demands.

The critical nature of the current water situation in the Mediterranean region is expected to be further aggravated by the impacts of climate change. The direct impacts of climate change registered in the Mediterranean basin consist of lower levels of precipitations, a modification of the intensity and distribution of the precipitations, an increase of floods, and a raise of temperatures. Climate change will amplify its substantial destabilizing effect on the hydrological cycle and will have a pervasive influence on the future demand, supply, and quality of fresh water resources in the region [5]. Imbalances between availability and demand, degradation of surface and groundwater quality, inter-sectorial competition, and inter-regional and international conflicts often occur, and are mostly obvious in the Mediterranean region. Innovations are therefore required particularly relative to irrigation management and practice as the agriculture sector is far ahead in demand for water in the region. Agriculture is therefore forced to find new approaches to cope with water scarcity, but coping in a sustainable way.

Rapid growth in the demand for high quality water, coupled with natural shortage and continuous restrictions in supply, has accelerated the search for alternative sources. The additional sources include fresh high quality run-off water, brackish water, and treated wastewater. In regions with limited natural water sources, treated wastewater, primarily in urban areas, can be utilized for agriculture, industry, recreation, and recharge of aquifers. Wastewater is a resource of growing global importance and its use in agriculture must be carefully managed in order to preserve the substantial benefits while minimizing the serious risks. Multiple complementary factors drive the increased use of wastewater in agriculture. Water scarcity, reliability of wastewater supply, lack of alternative water sources, livelihood and economic dependence, proximity to markets, and nutrient value all play an important role [6].

The Arab countries on the Mediterranean are Morocco, Tunisia, Algeria, Libya, Egypt, Palestine, Lebanon, Syria, and partially Jordan. They considerably differ with respect to their level of development, population, and natural resources. The common feature of all these countries is the mixture of human activities that produce liquid waste that has no other place to get rid of but the Mediterranean. The second common feature is that they all suffer from water scarcity in varying levels, which means that treated sewage could provide a source that could bridge part of the gap between supply and demand and therefore help to achieve MDGs through increased water availability and poverty reduction, besides contributing to food security, better nutrition, and sustenance of agricultural employment for many households [7].

Box 1. Water Scarcity in Southern Mediterranean Region
Málaga [5] reported that fresh water resources in the Mediterranean are under increasing pressure in terms of both quantity and quality and could be seen as follows:

- *Northern Mediterranean* countries with higher, more regular rainfall also face climate-induced natural hazards, flooding and water shortages, in basins susceptible to periodic drought. As a consequence, human and natural systems sensitive to water availability and water quality are increasingly stressed, or coming under threat. Those countries will have to face water quality degradation and meet the increasing needs of environmental protection and restoration.
- *South and East Mediterranean* counties where utilization is now approaching hydrological limits, and the combined effects of demographic growth, increased economic activity, and improved standards of living have increased competition for remaining resources. Water resources are already overexploited or are becoming so with likely future aggravation where demographic growth is strong. The Eastern countries will be more sensitive to short term or structural shortages in certain areas.

Average annual supply of water for the MENA region as a whole is now well under 1,500 m^3 per capita, and many nations fall below 500 m^3 [8]. The volume of per capita freshwater resources is an important indicator of the water endowment of a country. Morocco, Egypt, Algeria, Tunisia, and Libya are some of the southern Mediterranean countries. Taking into account both internal and external sources, their annual supply of water is about 1,000, 880, 470, 430, and 100 m^3 per capita respectively (Table 1). Water resources in the remaining countries are all below 500 m^3 per capita, per year, a threshold of severe water stress in the commonly cited water criticality classification [9]. At those levels, chronic water scarcity can be expected unless water is managed carefully and the economy is directed to low-water-consuming activities.

Table 1 The volume of per capita freshwater resources in six of the southern Mediterranean countries

	Algeria	Egypt	Israel	Libya	Morocco	Tunisia
Water resources, m^3 per capita, per year (1998)						
Internal	460	43	289	100	1,071	371
External	13	841	20	0	0	64
Total	473	884	309	100	1,071	435
Water withdrawal, m^3 per capita, per year						
	180 (1990)	921 (1993)	407 (1989)	880 (1994)	433 (1992)	376 (1990)
Irrigated areas, 1,000 ha						
1980	253	2,445	203	225	1,217	243
1985	338	2,497	233	300	1,245	300
1990	384	2,648	206	470	1,258	300
1995	555	3,283	199	470	1,258	361
1999	560	3,300	199	470	1,305	380
Changes %	121.34	34.97	−1.97	108.89	7.23	56.38
Irrigated area as % of total crop land						
	7	100	45.5	22	13	7.8

Source: [9]

2 Why Wastewater Reuse in Mediterranean Region?

The Mediterranean region is considered as one of the world's most water-stressed regions. Wastewater production is the only potential water source which will increase as the population grows and the demand on freshwater increases. Therefore, wastewater should be viewed as a resource which must be recovered and added to the water budget. If wastewater is recognized as part of the total water cycle and managed within the integrated water resources management (IWRM) process, this will help meet the requirement.

2.1 Help Closing the Gap Between Supply and Demand

In the last few years of the twentieth century, 3 billion people around the world lacked adequate sanitation and up to 95% of the wastewater was discharged in the environment without treatment. Around 5.5 billion people are expected to be without sanitation in 2035. The discharge of untreated wastewater is a waste of resources Euro-Mediterranean Regional Programme for Local Water Management (MEDA) Water International Conference on Sustainable Water management, see: http://www.semide.net/thematicdirs/events/sev802988).

In the Mediterranean region, nearly 70% of the available water resources are allocated to agriculture. The percentage decreases to 50% of the total available resources in the northern countries, and accounts for as much as 80% of the water consumed, especially in the southern countries like Egypt (Fig. 1). Wastewater reuse therefore could have a direct influence on a region's food security [10].

Wastewater reuse will continue to be a first option to augment the water resources for many years in the Region [11].

Wastewater reuse in the region can partially contribute to solving the problem of quality and quantity. Reusing of wastewater is considered one of the effective adaptation strategies in the water sector, which helps closing the demand–supply gap in water resources, through sustainable reclamation of wastewater, especially in agricultural sector [5]. This would also have a major role in agricultural economy, both on qualitative and quantitative basis, and also in the well-being and the health of the society.

The Mediterranean basin is nowadays depending for its economic and social development on agriculture, and secondarily on industry and other economic activities. Irrigated agriculture in competition with other sectors will face increasing problems of water quantity and quality, considering increasingly limited conventional water resources, growing future requirements, and a decrease in the volume of fresh water available for agriculture.

Agriculture will remain an important sector of economy in all Mediterranean countries. This is particularly true for the developing countries on the Mediterranean, which use export opportunities to neighboring countries and the European Union, but in order to satisfy the demand of these populations, agricultural production has still to be increased. This is not possible without available water resources for irrigation. Therefore, alternatives like the reuse of waste water in agriculture have to be seriously considered.

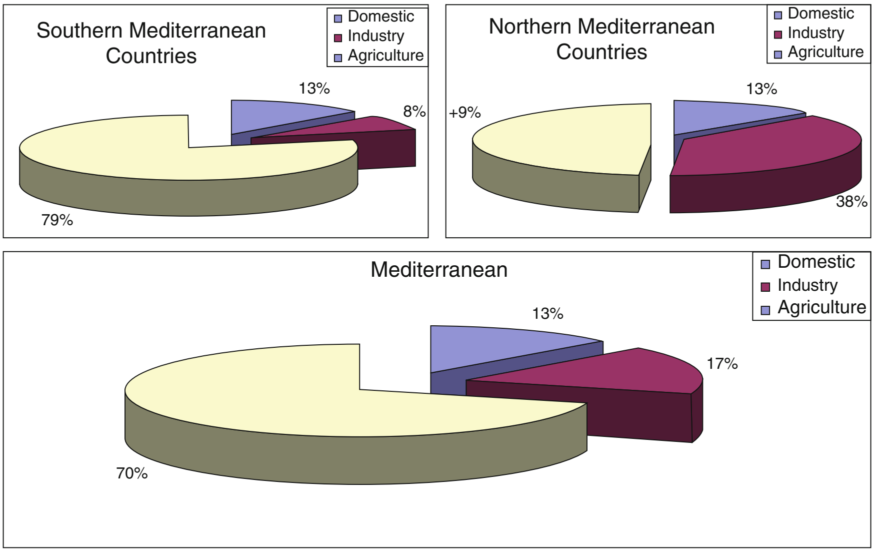

Fig. 1 Water use per sector in the Mediterranean
Source: [10]

2.2 Applying the Concept of Sustainability

One of the greatest challenges facing humanity is how to use scarce resources in an equitable and sustainable way. The Mediterranean region is undergoing rapid local, global, social, and environmental changes. All indicators point to an increase in environmental and water scarcity problems with negative implications towards current and future sustainability [12]. As the demand for water continues to rise, it is imperative that this limited resource is used efficiently and in sustainable way for agriculture and other purposes. Water recycling and reuse is meant to help close the gap in water cycle and therefore enable sustainable reuse of available water resources.

The responsible use of the water can be described in terms of sustainability or sustainable development. Many present day systems are "disposal-based linear systems." The traditional linear treatment systems must be transformed into the cyclical treatment to promote the conservation of water and nutrient resources. The reuse of the wastewater decreases the expenditure on fertilizers and it is considered safe as it has been treated for pathogens. Use of organic waste nutrient cycles, from point-of-generation to point-of-production, closes the resource loop and provides an approach for the management of valuable wastewater resources. Failing to recover organic wastewater from urban areas means a huge loss of life-supporting resources that instead of being used in agriculture for food production fill rivers with polluted water [13].

2.3 Prevents Fresh Water Resources and Water Bodies from Pollution

The world's freshwater resources are under strain. Reuse of wastewater, in concert with other water conservation strategies, can help lessen man-made stresses arising from pollution of receiving waters. Reuse will provide relief to the Mediterranean from the hazards of directing this water to its basin. Irrigation with treated municipal wastewater is considered an environmentally sound wastewater disposal practice compared to its direct disposal to the surface or ground water bodies. There are concomitant environmental risks with wastewater reuse, such as transport of harmful contaminants in soils, pollution of groundwater and surface-water, degradation of soil quality, e.g., salinization, impacts on plant growth, and the transmission of disease via the consumption of wastewater-irrigated vegetables. The challenge facing wastewater reuse is to minimize such risks so as to maximize the net environmental gain. Egypt's second urgent problem after scarcity is water quality. The Nile which is the major drinking water source is often below the minimum quality standards. A major reason is that only 36.1 % of the population is connected to the sewage network [14]. Therefore, a lot of untreated wastewater is released into the Nile. The amount of wastewater that is released into the Nile is 3.8 billion m/year, out of which only 35 % is treated properly [15].

Table 2 Impacts of some of Arab countries on the Mediterranean

Volume of wastewater/million cubic meters	Egypt	Syria	Jordan	Libya	Morroco	Tunisia
Treated and disposed in the Mediterranean	73					25
Untreated and disposed in the Mediterranean	12,000	210			40	50
Impacts on the Mediterranean (high-medium-low)	High	Low	Nil		Low	Low

Source: CEDARE [7]

At regional level, coastal cities of Mediterranean dispose their sewage both treated and untreated to the Mediterranean (in Morocco and Tunisia, 60% to 80% respectively of wastewater is discharged into the sea often without treatment).

As can be seen in Table 2, the mixture of land drainage, domestic, and industrial wastewater in Egypt is carried through the drainage network to the Mediterranean either directly or indirectly via the coastal lakes which are connected to the sea directly through sluices (such as Lakes Manzala, Borollous, and Edko) or by lifting (Lake Mariout). Finally almost 12 billion m^3 of drainage water takes its way to the Mediterranean every year [7].

However, the waste water treatment systems in developing countries (e.g., Egypt) are not successful and therefore unsustainable because they were simply copied from Western treatment systems without considering the appropriateness of the technology for the culture, land, and climate [44]. To ensure a high level of protection, the requirements of the respective legislations must be met, particularly where authorizations and monitoring is concerned. Furthermore, levels of pollutants in treated wastewater must be reduced to safe levels as determined through a risk management approach and, where appropriate, through the application of best available techniques [16].

Industry in most Mediterranean countries is still emerging. Most of the waste disposed into the Mediterranean is composed of domestic and municipal sewage except in the case of Egypt where agricultural land drainage, mixed with both industrial and municipal wastewater, is also disposed to the sea [7].

2.4 Provides a Mitigation Solution to Water Scarcity and Climate Change

Adapting to climate change will have close resonance with adapting to water scarcity and is likely to require implementation of water demand management strategies which may require capacity building and awareness raising across institutions and society. Adaptation measures on the supply-side include ways to improve rain-harvesting techniques, increasing extraction of ground water, water recycling, desalination, and improving water transportation. Climate change has many effects on the hydrological cycle and therefore on water resources systems. Global warming could result in changes in water availability and demand, as well as in the redistribution of water resources and in the structure and nature of water consumption, and exasperate conflicts among water users.

Wastewater reuse could provide a mitigation solution to climate change through the reduction in green house gases by using less energy for wastewater management compared to that for importing water, pumping deep groundwater, seawater desalination, or exporting wastewater [10]. Reuse increases the total available water supply and reduces the need to develop new water resources and therefore provides an adaptation solution to climate change or population density induced water scarcity by increasing water availability. It may also contribute to desertification control and desert recycling. As compared to industrialized countries, Egypt's CO_2 emissions are still considered low and are marginal on a global level. Further development of projects to reduce greenhouse gases emissions would offer Egypt an opportunity to upgrade its energy, transportation, and industrial sectors. One such project has been CO_2 "Sink" action. This is the action of planting trees that will capture carbon, thereby leading to an increase in Egypt's CO_2 absorptive capacity. At the turn of this decade, Egypt focused on afforestation with the aim of carbon sequestration, optimizing the use of scarce water resources and reducing sources of pollution through wastewater. In consequence, the Egyptian Environmental Affairs Agency (EEAA) has focused on the implementation of the national program in water reuse for forest plantation. This program has been implemented in 24 different regions in 16 governorates. Around 5,500 and 5,700 feddans were planted during 2004 and 2005, respectively. A further 890 and 1,000 feddans were added in 2006 and 2007, respectively. This means that the current share of land area covered by forests is around 5.41% of the total area of the country [17].

2.5 Help Achieving Millennium Development Goals

Treated sewage could provide a source that fills part of the gap between supply and demand and therefore help to achieve MDGs through increased water availability and poverty reduction through the use of appropriate technology solutions. It contributes to food security and better nutrition, and sustains agricultural employment for many households [7].

3 Egyptian Water Policies and the Right to Water

Access to a regular supply of safe water is a basic human right, as is the access to unadulterated food. But as with other human rights, too many people miss out. Of the world's population of 6 billion people, at least 1.1 billion do not have to access to safe drinking water and more than 2 billion people lack proper sanitation. Making more water available to communities can improve families' incomes, for instance by boosting crop production and the health of livestock.

As the former United Nations Secretary-General Kofi Annan said [45] "Access to safe water is a fundamental human need and, therefore, a basic human right. Contaminated water jeopardizes both the physical and social health of all people."

It is an affront to human dignity. The right to water has been mentioned early in 1948 in Article 25 of the Universal Declaration of Human Rights. In 1992, the United Nations proclaimed that water should be considered to be a human right. This position, however, has not been accepted by many developed and developing countries.

To date, the right to water has been recognized in a number of non-binding UN resolutions and declarations, the most important of these being the 2002 General Comment #15 by the UN Committee on Economic, Social, and Cultural Rights, which defines the human right to water as "entitling everyone to sufficient, safe, acceptable, physically accessible and affordable water for personal and domestic uses."

At present, nearly all the discussions on water as a human right have been almost exclusively targeted to drinking water and sanitation-related issues. While unquestionably, availability of clean drinking water and access to sanitation are important societal and environmental requirements, water also has other equally important uses in terms of agriculture, energy production, industrial and regional development, environmental conservation, tourism, etc.

In response to all the challenges that are facing water resources management in Egypt, the Egyptian Ministry of Water Resources and Irrigation (MWRI) has adopted new IWRM policies to achieve sustainability in water resources utilization for current and future generations. The water policies adopted by MWRI consider water primarily as a human right, and contain several measures to ensure this consideration. One of the major challenges facing the water sector in most Mediterranean countries including Egypt is closing the rapidly increasing gap between the limited water resources and the escalating water demands in the municipal, industrial, and agricultural sectors. To cope up with this challenge, the MWRI has developed a National Water Resources Plan (NWRP) with three major steps: (1) development of additional water resources and cooperation with the Nile Basin Riparian countries; (2) making better use of the existing water resources and increasing water use efficiency; and (3) protection of water quality and the environment. This national plan describes how Egypt will safeguard its water resources (quantity and quality) under the conditions of an increasing population and a fixed water availability and how it will use the resources in a sustainable and responsible way from a socio-economic and environmental point of view. The planning horizon covers a period of 20 years from 1997 up to 2017 [18].

The concept of water as a human right is not a trivial task, especially in a country like Egypt with a lot of pressure on its water resources. Pressure on Egypt's water resources comes from several sides, and delays achieving the whole right to water to some extent.

As shown in Fig. 2, there has been a rapid decline in the per capita share of water in light of Egypt's fixed Nile water quota, which is currently 55.5 BCM annually. Average annual per capita share, which was almost 1,000 m^3 in the early 1990s, will reach 600 m^3 in 2020, and decline to 400 m^3 by 2030 if the current birth rate continues [17].

Government policy has aimed at increasing the efficiency of water utilities and to implement its National Water Quality Management Program.

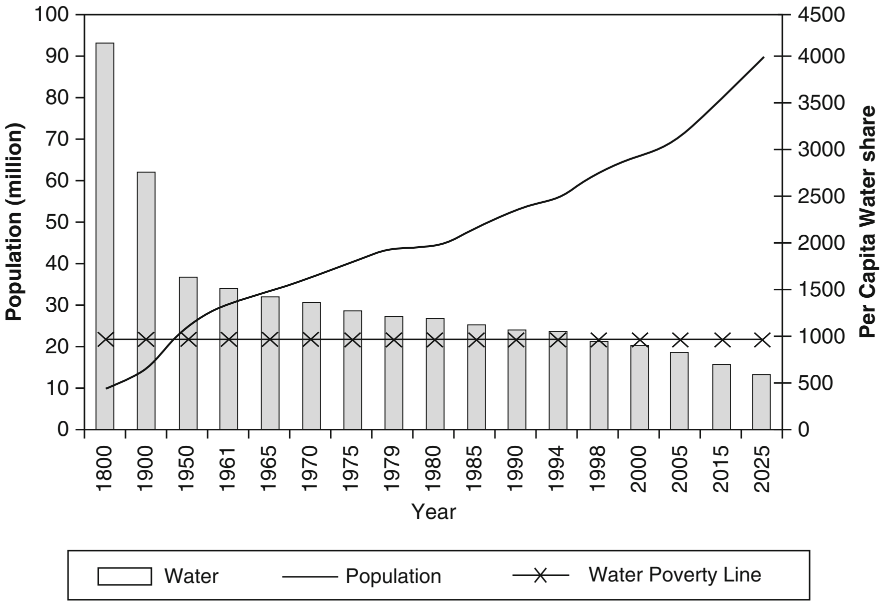

Fig. 2 Population growth and per capita water share in Egypt (m^3/year)
Source: [18]

Finally revision of consumption patterns, introduction of new methods to evaluate the financial efficiency of water projects, introduction of simpler and/or cleaner technologies, fostering public participation, and dissemination of information and education are all concepts to be put to work together to achieve the goal of universal access to safe water and adequate sanitation [19].

Box 2. Pressure on Egypt's Water Resources

- Geopolitical dimension: Egypt receives about 98% of its fresh water from the Nile, originating outside its international borders. This is considered a major challenge for Egyptian water policy and decision makers.
- The physical scarcity of water to satisfy and sustain the life and development. The demand is rocketing and the available renewable quantity is diminishing because of unsustainable extraction, weather changes, population growth, urbanization, and agricultural and industrial expansions.

The population is expected to grow to 88.8 million persons by 2017. Urban water demand is expected to grow by about 47%, from 4.5 km^3 in 2000 to 6.6 km^3 in 2017. Growth in industrial capacity is expected to increase industrial demand for water by about 40%, from 7.6 km^3 in 2000 to 10.6 km^3 in 2017. An aggressive horizontal expansion program plans to increase irrigated lands about 44%, from 7.8 million feddans in the year 2000 to 11.2 million feddans by the year 2017. Expansion areas are underway or are completed for a total 2.4 million feddans. In 2000, 38 km^3 of water was consumed by vegetation and soil surface evapotranspiration and about 2.1 km^3 of water evaporated from the Nile River and irrigation canal [20].

- Non-existence of the economic value for water in the country; this is promoting the misuse and exhausting the resources, and exacerbates water pollution.
- Institutional inefficiency is one of the major constraints in managing the sector. Lack of bylaws or their enforcement, political domination of the decision-making, and short-term planning are instances.
- Inadequate financing systems exist in most of the countries of the region, which mainly depend on subsidy. There is a need to reform the sector to operate on self-sufficient principles and cost recovery.

Saqer Al Salem (2003) available at: http://www2.mre.gov.br/aspa/semiar-ido/data/Palestra%20Saqer%20Al%20Salem%20texto.doc

4 Climate Change and Egyptian Water Resources

As water affects human lives, mankind also has an effect on the hydrological cycle of the planet, in all dimensions from the very local to the global scale. Climate change is now a scientifically established fact. There is scientific consensus that the global climate is changing mainly due to man-made emissions.

The current water scarcity will be intensified by a further decrease in water availability due to reduced rainfall, which is projected to decrease by 20% over the next 50 years [21]. Meanwhile, water demand will increase as a result of rising temperatures that lead to increase in evapotranspiration from irrigated agricultural zones and natural ecosystems [22]. A decrease in rainfall and an increase in temperatures are projected to contribute to increased evaporation and decreased groundwater recharge. Projections strongly indicate that the large river basins in the Middle East region (e.g., river Nile) will experience major decreases in water levels. Results from an EU Mediterranean project supported these projections and indicated that there will be general and continuous drought conditions with increases in water deficits in the Mediterranean region [23].

It is expected that such dry conditions and rainfall decreases will put more pressure on available water resources, especially in the major river basins of the region, which will also be influenced by the increase in water demands in the upstream areas of these rivers. This phenomenon will trigger more competition over water resources. Finally, increasing temperatures and the associated sea level rise will result in seawater intrusion in these rivers deltas and coastal groundwater aquifers [12].

Recent studies, including the 2007 IPCC assessment report, indicate that MENA region (including Egypt), despite its less than 5% contribution to gas emissions, will be significantly affected by climate change. In the eastern Mediterranean in particular, there is a consensus that climate change and the frequency of some extreme weather events like drought and floods will continue to rise [24]. There is a consensus that most of the arid and semi-arid regions of the world can expect an increase in water stress because of the impacts of climate change.

Climate change will put additional pressures on stressed ecosystems in Mediterranean region. As a result of the temperature rise, the water demand will increase. The evaporation from water bodies will reduce the available supply, and the increased evapotranspiration from crops and natural vegetation as well as the water demand for irrigation or industrial cooling systems will add pressure on water resources. Water quality will be affected by higher runoff which will increase pollution because of agricultural chemicals and less capacity to assimilate pollution with lower flows. The intensification of rainfall will primarily be responsible for soil erosion, leaching of agricultural chemicals, and runoff of urban and livestock wastes and nutrients into water bodies. Watershed conditions will suffer from erosion and desertification processes due to hotter and dryer summers, as well as more frequent and prolonged droughts coupled with rainfall events. The higher temperatures would dry soils and increase salinization and generate a higher incidence of wind-blown soil erosion [5].

Probably, the biggest impact of climate change in the Mediterranean region will be on food security due to the projected decrease in the available water resources and agricultural production. It is therefore necessary to prepare and appropriately respond to the potential negative impacts of climate change, many of which have already materialized, by considering these potential impacts on the water resources planning and integrating the appropriate adaptation measures in the water programs.

The management of the decreasing water resources, as a result of the climatic changes within the Mediterranean region, is challenged in particular, as climate change coincides with high development pressures, increasing populations, and high agricultural demands.

Egypt appears to be particularly vulnerable to climate change, because of its dependence on the Nile River as the primary water source, its large traditional agricultural base, and its long coastline, already undergoing both intensified development and erosion. Equally serious is the potential effect of the sea-level rise resulting from the thermal expansion of seawater and the melting of land-based glaciers. Even a slight rise in the sea-level will exacerbate the already active process of coastal erosion along the shores of the Delta, a process that accelerated after the building of the Aswan High Dam. Sea level rise will also accelerate the intrusion of saline water into the surface bodies of water (the lagoons and lakes in the northern Delta). The rise in the base level of drainage will further increase the tendency toward water logging and salinization of low-lying lands, with the consequence that significant areas will become unsuitable for agriculture. At the very least, the costs of drainage will increase [12].

Adaptation strategies of Mediterranean regions to threat of climate change on water resources require an optimization of water management for each use, as well as efficiency improvements. One of the effective adaptation strategies in the Water Sector is closing the demand–supply gap in water resources by optimizing reclamation of wastewater in a sustainable manner, especially in agricultural sector which accounts for about 79% in southern Mediterranean region [5]. Much can be done to mitigate the potential dire consequences of climate change and the earlier the task is recognized and undertaken, the more likely it is to succeed. A few essential changes in resource management would lead not only to adaptation to climate change, but also to the overall improvement of the Egyptian agricultural system.

5 Egyptian Water Policy and the Millennium Development Goals

MDGs are a set of quantified objectives with concrete target times that arise from the Millennium Declaration that has been adopted by all members of the United Nations in 2000. All the 191 UN member countries have pledged to meet these goals by the year 2015. The UN Millennium Project in 2004 highlighted that water is an essential element in achieving most of the MDGs; therefore, good quality water should be available to all to meet their needs and this objective should be achieved in a manner that is secure and sustainable and does not damage the ecosystems.

Using 1990 as a baseline, goal 7 of MDGs seeks to reduce by half the proportion of people without sustainable access to safe drinking water by 2015. At the global level, countries are on track to meeting the target for improving access to safe drinking water. But some areas are performing better than others, highlighting a growth in regional disparities in access to safe drinking water (MDG Progress on Access to Safe Drinking Water by Region: available at: http://www.worldwater.org/www/data20082009/Table5.pdf).

In North Africa, the overall situation with respect to the trends and to achieving the MDGs is fairly positive. This is particularly the case in Tunisia, Egypt, and Libya. Morocco and Algeria have not been progressing at the required rate in order to reach the MDGs, and the two countries must reverse the direction of development in order to achieve the targets.

The UNDP made a comprehensive assessment of the trends and prospects of the world's countries to achieve the MDGs in the Human Development Report of 2003 [25]. The progress in achieving the MDGs in relation to water within the MENA region was reported by Egyptian Ministry of Economic Development [17]. The MENA region consists of 23 countries including Egypt. The region faces huge challenges in achieving the MDGs and improving the water and sanitation coverage in the way required. The implementation of the MDGs appears to be extremely difficult for all countries in the region especially with respect to sanitary sewage projects [7].

Egypt believes that improved water resources management and access to water supply and sanitation have benefits for each of the eight MDGs. Egypt is facing a number of environmental challenges mainly because of rapid population growth and the necessity for extensive development to meet the needs of the growing population. This has placed pressure on natural resources following expansion in industrial, agricultural, and tourism activities. Consequently, Egypt has directed significant concern to resolve the pressing environmental problems by taking several measures – including ratifying various international environmental conventions and treaties – that are to be harmonized into the national legislative framework. In 2000, Egypt agreed to achieve the MDG by the year 2015.

As indicated in the fourth follow-up report on achieving the MDGs for Egypt, at the national level, Egypt is on the right track to realizing most of the MDGs by the set date of 2015, but regional disparities still need to be adequately addressed. Egypt is making significant strides towards achieving these MDGs starting from the National Environmental Action Plan (2002–2017) which emphasizes the changes needed in the areas of water, sanitation, energy, and biodiversity. Egypt has taken serious steps towards achieving the MDG by investing heavily in the water sector, through major irrigation projects, drinking water supply, and sanitation infrastructure. It has also played a central role in cooperating with other Nile riparian countries on water resources [17].

The MDGs call for halving the proportion of people without access to improved sanitation or water by 2015. In this regard, drinking water in Egypt, is well supplied with a high rate of satisfaction of the demand, reaching 100% in urban areas and 95% in rural areas (Fig. 3a). The rural population that has access to adequate drinking water has increased from 45% in 1993 to about 95% in 2004, distributed over 4,617 villages in Egypt [18].

The per capita share of service increased from 130 l/day for drinking water in 1982 to 275 l/day in 2004. According to the data published by the Cabinet Information and Decision Support Center, the total installed capacity of drinking water treatment plants is 21 million m^3/day in 2004 (Fig. 3b) [18]. In rural Egypt, problems of low continuity or reliability of piped water supply can be found.

Sanitation services in Egypt are less developed than water supply services. At present, there are more than 200 wastewater treatment plants in the country. Urban coverage with improved sanitation gradually increased from 45% in 1993 to 56% in 2004. In contrast, rural sanitation coverage remains incredibly low at 4% (Fig. 4a). The low coverage, in combination with a sub-optimal treatment, results in serious problems of water pollution and degradation of health conditions because the majority of villages and rural areas discharge their raw domestic wastewater directly into the waterways [18].

The capacity of wastewater treatment plants has increased by 10 times in the last two decades (Fig. 4b). The existing capacity of 11 million m^3/day serves about 18 million people in mainly urban areas. The total capacity will reach 16 million m^3/day by 2007, serving all urban areas. Population with access to improved sanitation has decreased over the period from 2004 to 2006. Disparities are apparent between and within governorates and the latter disparities are due to discrepancy between urban and rural regions [18].

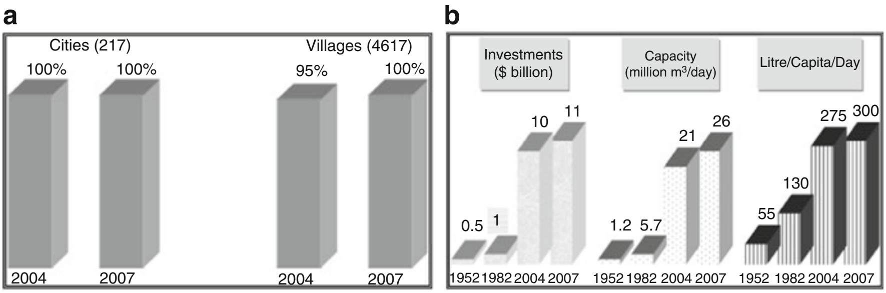

Fig. 3 (**a**) Drinking water service coverage in Egypt. (**b**) Drinking water service development in Egypt
Source: [18]

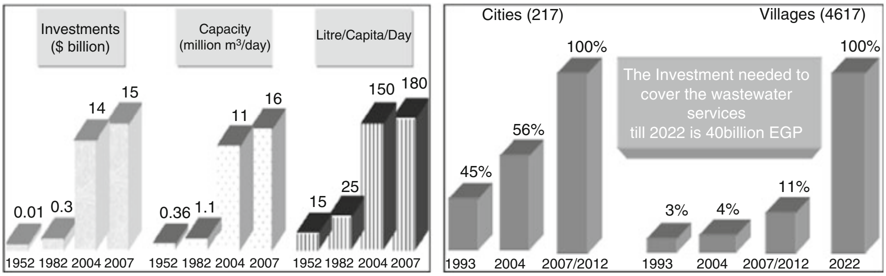

Fig. 4 (**a**) Wastewater service development in Egypt. (**b**) Wastewater service coverage in Egypt
Source: [18]

Unfortunately, the story is not so positive for rural areas which need more intensive programs and policies in order to reach the MDG target. However, recent figures from the 2006 Population Census reveal a decrease in coverage. Therefore, in spite of continuous government efforts to extend water service to all urban and rural population, the service does not catch up with rapid population growth, and hence service coverage is worsening. Though the access level still meets the 2015 target, the challenge facing the government is to sustain it. Moreover, these figures do not reveal the disparities that exist between governorates [17].

6 Wastewater Reuse in the Mediterranean

6.1 History of Wastewater Reuse in the Region

Wastewater in the Mediterranean is widely recognized as a significant, growing, and reliable water source, and reuse is increasingly becoming integrated in the planning and development of water resources in the region [26]. Many MENA countries practice wastewater treatment and reuse, whether planned or un-planned. According to World Bank [27], on average, across the region of MENA, 2% of water use comes from treated wastewater. The Gulf countries use about 40% of the treated wastewater to irrigate non-edible crops for fodder and landscaping. The management and reuse of wastewater in the Mediterranean varies from country to country (Jordan is reusing up to 85% of treated wastewater and Tunisia 20–30%), as do the criteria and their enforcement [28]. Some countries have no wastewater treatment facilities and direct reuse of raw wastewater is occurring with serious health hazards and environmental problems. Others have a well-established national reuse policy. Moreover, wastewater treatment and reuse criteria differ from one country to another and even within a given country such as in Italy and Spain. Some of the main discrepancies in the criteria are, in part, due to differences in approaches to public health and environmental protection. For example, some countries have taken the approach of minimizing any risk and have elaborated regulations close to the California's Title 22 effluent reuse criteria, whereas the approach of other countries is essentially a reasonable anticipation of adverse effects resulting in the adoption of a set of water quality criteria. This has led to substantial differences in the criteria adopted by Mediterranean countries. However, the current situation in some developing countries in the region is the direct use of untreated wastewater for irrigation without taking into account the stated guidelines and standards, and associated risks.

At present, wastewater is mainly reused in the Mediterranean for agriculture. Other uses, like industry and urban use, are being developed at a good pace; but especially golf courses and some industries are increasingly using waste water [29]. In addition to providing a low cost water source, the use of treated wastewater for irrigation in agriculture combines three advantages. First, using the fertilizing properties of the water eliminates part of the demand for synthetic fertilizers and contributes to decrease in the level of nutrients in rivers. Second, the practice increases the available agricultural water resources and third, it may eliminate the need for expensive tertiary treatment. Irrigation with recycled water also appears to give some interesting effects on the soil and on the crops. As a result, the use of recycled wastewater for irrigation has been progressively adopted by virtually all Mediterranean countries. Because irrigation is by far the largest water use in the region and the quality requirements are usually the easiest to achieve among the various types of wastewater reclamation and reuse, it is by far the largest reuse application in terms of volume.

However, in various Mediterranean societies, some constraints need to be overcome, such as (a) recycled wastewater quality prior to reuse in relation to public health, (b) public awareness, (c) the absence of water law, regulating bodies and guidelines, and/or criteria for reusing water [7]. Not every country in the region has established its national guidelines which is a necessity for planning safe reuse of treated wastewater for irrigation. Most of the wastewater reuse standards in MENA are on the basis of either United States Environmental Protection Agency (USEPA) or World Health Organization (WHO) guidelines. However, most of the time, these standards are not reinforced in the countries of the region [28].

6.2 *Wastewater Reuse, Egyptian Experience*

6.2.1 Background

In many ways, Egypt is a typical developing country, characterized by a high population growth (78.7 million until May 2008, [30]), accompanied by increased rates of water consumption. These features tend to elevate water demand, which has an adverse influence on water resources. Water is the fundamental element for sustainable and integrated development in Egypt. Horizontal expansion in agriculture is connected to the country's ability to provide the water required for that expansion. Moreover, the economics of water use and its future on the long run require searching for alternatives and determining the water resources available at present and additional resources we can obtain in the future. The water sector in Egypt is facing many challenges including water scarcity and deterioration of water quality because of population increase and lack of financial resources. Fragmentation of water management and lack of awareness about water challenges are also a problem. Further, more technical and financial assistances might be essential at this stage for numerous ambitious programs. The national water balance prepared for Egypt indicated that there was an overall deficit of approximately 8 billion m^3. This shortage was compensated for by raising the efficiency of available water resources utilization through reuse of drainage water and the use of ground water [31].

The present per capita water share is below 1,000 m^3/year (see Fig. 2) and it might reach 600 m^3/year in the year 2025, which would indicate water scarcity (water scarcity level starts at 1,000 m^3/year). In addition, rapid degradation in surface and groundwater quality results in less water being available for different uses [18]. Figure 6 illustrates the future water requirement till year 2017 in Egypt.

6.2.2 Major Use of Wastewater in Egypt

Wastewater Reuse History

Treated wastewater (after primary treatment) has been in use since 1911 in agriculture (Gabal Al Asfar farm: 3,000 feddans). Yet, experience of large scale, planned and regulated reuse project is still limited. Large scale pilot projects (167,000 feddans) are in East Cairo, Abu Rawash, Sadat City, Luxor, and Ismailia. In the mean time, most of the sewage water drained to the agricultural drains is actually reused in one way or another (*indirect reuse*). No industrial reuse schemes and no groundwater recharge exist in Egypt [32].

Egypt practices the use of various types of marginal quality water, such as agricultural drainage water, treated domestic wastewater, and desalinated brackish water. Egypt is a unique country in the region and agriculture depends mainly on irrigation. The environment conditions controlling agriculture, e.g., clay soil, arid climate, and intensive agriculture, need an intensive efficient drainage system. This results in huge amounts of agricultural drainage water. Wastewater includes treated

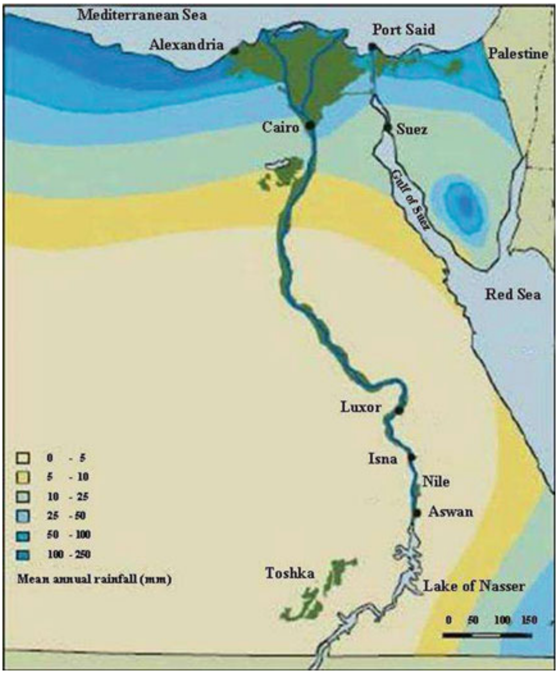

Fig. 5 Distribution of rain in Egypt
Source: [46]

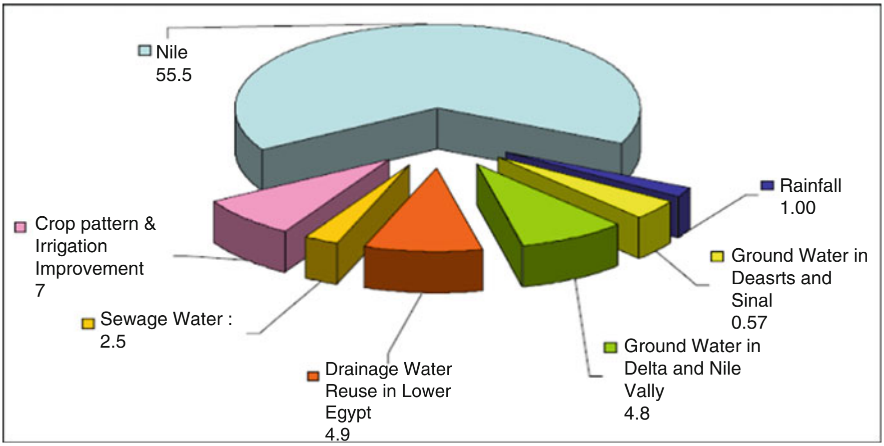

Fig. 6 Future water requirement till the year 2017 in Egypt
Source: [31]

and untreated municipal sewage and industrial effluents, in addition to agricultural drainage, which are considered as non-conventional water resources. Drainage water reuse is practiced on a very large scale. The official reuse of agricultural drainage water in irrigation amounted to 4.84 km^3/year in 2001. The present aim of the Government of Egypt is to reuse up to 8 km^3/year in new reclamation areas in the near future. In addition, there exists significant unofficial wastewater reuse estimated between 2.8 and 4 km^3. This unofficial water reuse is not controlled by the government and poses threats. If adequate regulations are not enforced, the quality of drainage water is threatened [28]. The strategy for the reuse of treated effluents in Egypt is on the basis of the fact that adequately treated wastewater effluents are a precious resource. No reuse guidelines have yet been adopted in Egypt, but the 1984 martial law regulation prohibits the use of effluent for irrigating crops, unless treated to the required standards for agricultural drainage water. The irrigation of vegetables eaten raw with treated wastewater, regardless of its quality level, is also forbidden. The Ministry of Agriculture advocates the restricted reuse of treated wastewater for cultivation of non-food crops such as timber trees and green belts in the desert to fix sand dunes. But on the other hand, the farmers use waste water as a source to irrigate all kinds of crops if alternative irrigation water is not available.

From the institutional standpoint, seven ministries are involved in wastewater treatment and reuse in the country, with unclear delineation of responsibilities and limited coordination among them. The situation is further worsened by the absence of clear policies and action plan on wastewater management as well as by standards that are practically impossible to enforce and which limit the effectiveness of pollution control abatement efforts. Dissemination of information among various organizations and to the public is limited, which substantiates the need for increased awareness and capacity strengthening regarding water quality management issues [33].

The Egyptian water strategy comprises the treatment and reuse of treated wastewater. Treatment of domestic wastewater is either primary or secondary (Table 3). At present, wastewater is estimated at 4,930 Mm/year, with 121 operational wastewater treatment plants, and about 150 plants under construction. The total capacity of the installed treatment plants amounts to about 1.752 billion m/year [4]. However, an accurate estimation of the total quantity or reused effluent is difficult to perform because of the many uncontrolled sources flowing into the same drainage canals. Furthermore, irrigation drainage waters are sometimes put into direct reuse, albeit unofficially, or directed towards canals. Unofficial reuse in the delta area alone has been estimated to range from 4 to 6 billion m^3/year. There are gaps between the available treatment capacity and the demands for treatment, so full treatment of urban wastewater will not be possible soon. The total wastewater quantity treated was estimated at 5.228 million cubic meters (MCM) per day in 2000 compared with 1.78 MCM per day in 1994 [34]. Table 3 shows the type and capacity of existing wastewater treatment plants in Egypt. There are two huge wastewater projects in Egypt, the greater Cairo wastewater project and the Alexandria wastewater project. The former serves some 20 million people. It serves a total area of 1,100 square kilometers and should provide a treatment capacity of 6.28 MCM per day by the year 2010 [3].

Table 3 Operational wastewater treatment facilities

Region treatment plant/facility	Type of treatment	Discharge towards	Capacity (1,000 m^3/day)
Upper Egypt			
8 Treatment plants	Aerated oxidation pond 7 trickling filter	Mainly agricultural drains, few to the River Nile	120
Greater Cairo			
Helwan	Activated sludge	Agricultural drains	420
Alberka	Activated sludge	Agricultural drains	300
Shoubra El-Kheima	Activated sludge	Agricultural drains	300
Zenin	Activated sludge	Agricultural drains	300
Abu Rawash	Primary	Agricultural drains	500
Gabal El-Assfar	Activated sludge	Agricultural drains	500
Delta			
Zagazig	Trickling filter, aerated oxidation ponds	Agricultural drains	95
			300
35 Other facilities	Extended aeration, trickling filter, activated sludge	Agricultural drains and lake Manzala	
EL – Mansoura			102.2
Alexandria			796

Source: [47]

According to Shaalan [48], the major problems and issues related to the current use of treated sewage water in Egypt are the following: (a) not enough infrastructure (treatment plants) to treat the amounts of wastewater produced, (b) only about 50% and 3% of the urban and rural populations, respectively, are connected to sewerage systems, (c) a significant volume of wastewater enters directly into water bodies without any treatment, (d) many wastewater treatment facilities are overloaded and/or not operating properly, (e) some industries still discharge their wastewater with limited or no treatment into natural water bodies, (f) domestic and industrial solid wastes are mainly deposited at uncontrolled sites and/or dumped into water bodies (especially outside Greater Cairo), (g) the quality of treated wastewater differs from one treatment station to another, depending on inflow quality, treatment level, plant operation efficiency, and other factors, and (h) negative impacts of the above problems on both health and environment [35].

Agricultural Drainage Canals (Indirect Reuse of Waste Water)

The majority of sewage water, amounting to more than 2 BCM/year, is discharged into agricultural drainage canals (Table 3). Part of this water receives secondary treatment while the rest is drained after primary treatment or raw. The present water management system strongly depends on the reuse of drainage water, as all the drainage water of Upper Egypt is discharged into the Nile (about 2.6 BCM/year). Drainage water in the Delta is recycled for irrigation by mixing part of the flow of the main drainage system with water in the main irrigation canals. Various reuse pumping stations in the Delta and Fayoum convey drainage water back into the irrigation canal system and into the Nile. Using the water twice or even three times increases the salinity up to the order of 3,000 ppm or more in drains near the lakes boarding the Mediterranean Sea. The mixing of drainage water with relatively clean irrigation water further diffuses all kinds of constituents, and negative environmental and health impacts are very much related to the big load of municipal wastewater discharge [36].

Since the mid 1970s drainage water reuse in irrigation became an official policy and a component of the NWRP. Institutional arrangements were set in place for implementing the drainage water reuse policy. Law 48 of 1984 was issued with bylaws and water quality standards that govern the disposal and reuse of drainage water. Network for monitoring drainage water quantity and quality was established since 1976 (Fig. 7) to provide real time information for drainage water disposal and reuse management on safe and sustainable basis [49]. According to MWRI/USAID, Appendix 2 [36], full treatment of wastewater is far from reality. Agricultural drainage reuse is a mainstay and will continue in the Delta. An alternative to agricultural drains as wastewater dumping sites is not available and long-distance diversion of wastewater is impractical. Given these factors, a central need for minimizing wastewater or separating it from general irrigation water remains. Separation of wastewater will require the following measures:

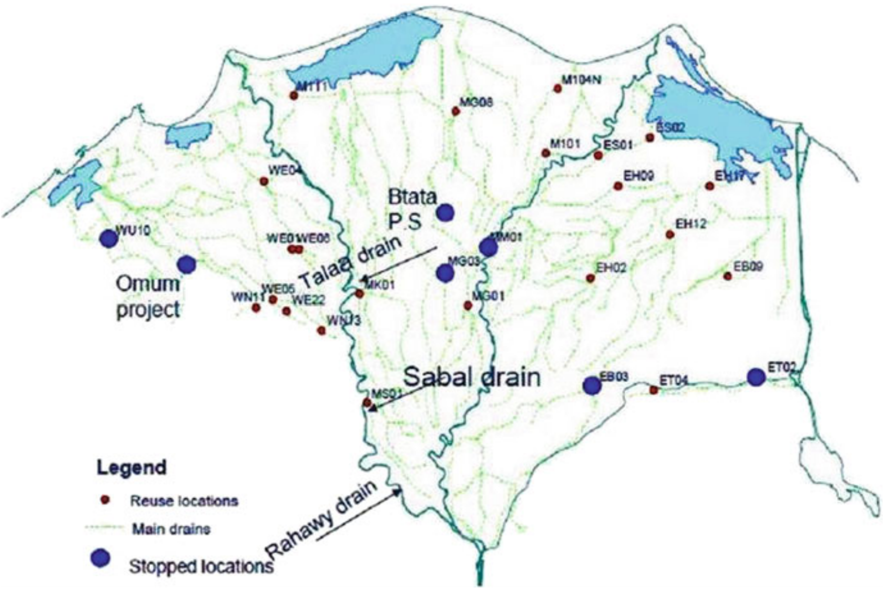

Fig. 7 Drainage network
Source: [37]

Classifying Drains into Two Categories: Reuse Drain and Discharge Drain

Drainage water is loaded with different sorts of pollutants from agricultural, industrial, or domestic sources. Salts, nutrients, and pesticides run off of irrigated fields and are carried by drainage water. Untreated industrial effluents discharged into the drains contain heavy metals and organic materials. Similarly, untreated domestic wastewater containing organic materials, bacteria, and pathogens is disposed into drains.

On the national level, both the Ministry of Agriculture and Land Reclamation (MALR) and the MWRI have agreed on a plan to reclaim an area of 1.2 million hectares by the year 2017, utilizing both treated wastewater and drainage waters. However, an accurate estimation of the total quantity of reused effluent in Egypt is difficult to perform because of the many uncontrolled sources flowing into the same drainage canals. Effluent reuse for industrial purposes is minimal because many industrialists have reservations about negative impacts treated wastewater might have on machinery. Nonetheless, industries have been prompted to treat and reuse their effluents whenever possible through the enforcement of Environmental Law 4/1994. The national legislation on effluent reuse has also recently been revised by Decree 44/2000 to bring the standards for effluent quality and conditions of reuse in line with those adopted internationally. Law 48/1982 imposes legal constraints on effluent reuse for aquifer recharge purposes but there are several concerns about identifying the lines dividing aquifers of drinking water quality from those of non-potable quality [38].

On the basis of Egyptian National Committee on Irrigation and Drainage (ENCID) [20], the strategies for drainage water reuse include the following measures:

- Increasing the reuse of drainage water from about 4.5 BCM/year to 9.0 BCM/year by year 2017 with average salinity of 1,170 ppm. This could be achieved through implementing several projects to expand the reuse capacity at different areas. Main future projects include the El-Salam canal project, the El-Omoom, and El-Batts drainage project.
- Improving the quality of drainage water especially in the main drains.
- Separating sewage and industrial wastewater collection systems from the drainage system.
- Draining 50% of the total generated drainage water in the delta into the sea to prevent seawater intrusion, and to maintain the salt balance of the system.
- Implementing an integrated information system for water quality monitoring in drains using the existing data collection network after updating and upgrading. Continuous monitoring and evaluation of the environmental impacts due to the implementation of drainage water reuse policy especially on soil characteristics, cultivated crops, and health conditions.
- Limiting the use of treated wastewater to cultivated non-food crops such as cotton, flax, and trees.
- Separating industrial wastewater from domestic sewage, so that it would be easier to treat domestic sewage with minor costs and avoid the intensive chemical treatment needed for industrial wastewater.

El-Salam Canal, an Egyptian Case Study

El-Salam canal is an example for using drainage water on large scale projects. The cultivated and cropped areas have increased over the past few years and will continue to increase because of the government policy to add more agricultural lands. To overcome the increased demand for food, the MWRI in collaboration with the MALR has planned an ambitious program to reclaim approximately 7,170 km^2 by 2010. Some of the reclaimed areas will be irrigated by mixing the Nile water with drainage water, such as that of the El-Salam Canal, which will cross the Suez Canal to reclaim 2.605 km^2 in Northern Sinai [31].

The Government of Egypt implemented El-Salam Canal project to reuse drainage water, to create new communities along the Canal, and to re-charting Egypt's population map. The Canal is designed to serve as the main source of irrigation water to the newly developed areas of the North Sinai Peninsula and the desert land to the west of the Suez Canal (643,560 acres of new lands). The Project is perhaps one of the most significant and controversial irrigation projects currently underway in the Eastern Nile Delta. Under the proposed management scheme, approximately 4 BCM/year will be delivered by the canal. Water supplied by this important new waterway will be composed of one part drain water and one part fresh water diverted from the River Nile (2 BCM/year). The ratio of Nile water to drainage water is about 1:1. This ratio is determined to reach total dissolved solids (TDS) not more than 1,000–1,200 mg/L to be suitable for cultivated crops [39].

Figure 8 shows the location of El Salam Canal Irrigation project, and the three sources of water to feed the canal [40]:

– Domietta Branch, which supplies the canal with 9 MCM per day.
– Hadous drain, which supplies the canal with 5 MCM per day, to be increased to 7 MCM per day.
– Serw drain, which supplies the canal with 2 MCM per day.

The Canal and its branches extend over a length of 262 km. The Canal project is divided into two phases:

First Phase: (West of Suez Canal) El-Salam Canal extends at a length of 87 km from the River Nile till the Suez Canal. It serves 220,000 feddans.

Second Phase: (East of the Suez Canal in Sinai) this phase includes establishing El-Salam Lake culvert below the Suez Canal to transfer the Nile water to Sinai. It serves an area of 400,000 feddans in Sinai.

The total amount of industrial wastewater feeding into the Salam canal through these sources is estimated at 170 MCM per year. These waters come to the drain through a group of secondary drains. These secondary drains are the receiving bodies of the industrial discharge from 14 large industrial facilities located in the Dakahlia Governorate, east of the Domietta Branch. These plants discharge about 27 MCM annually (15 MCM of industrial discharge, 10 MCM cooling waters, and 2 MCM of domestic sewage) [40].

Table 4 shows the water quality and estimated pollution load in El Salam canal after receiving waters from the three main sources.

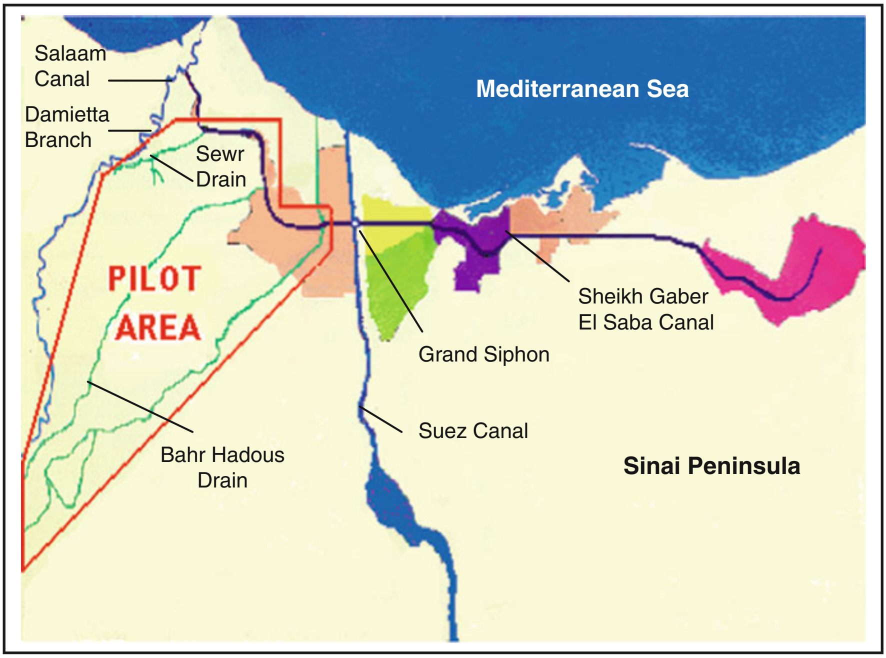

Fig. 8 Location of El Salam Canal irrigation project and the three sources of water to feed the canal
Source: [40]

Table 4 Water quality along El Salam canal

Pollutant	Load (tons/day)	MOH analysis, Mar 2000
BOD	35	22
COD	100	37
Oil & Grease	25	5
Suspended Solids	80	–
Total dissolved solids	160	1,140

Source: Appendix 4 [41]

The water of El Salam canal receives high loads of pollutants every day. However, through its long journey of about 180 km, most of the suspended matter, oils, and grease are precipitated; in addition to the partial removal of COD and BOD. Because of this natural cleaning process, testing of the quality of the canal's waters before crossing of the Suez canal revealed a high degree of transparency [41].

The MWRI adopted a policy aimed at improving the quality of waters feeding the El Salam canal from the drains of the East Delta region and the reused drainage water in the Middle Delta region. This policy is on the basis of encouraging/forcing industrial facilities in these regions to control their industrial pollution [41].

Forest Plantation

The use of sewage water to develop forests in deserts represents a challenge for the Undersecretary for Afforestation and Environment, MALR. Since the early 1990s, the Undersecretary, with support of donors and international agencies for development, has actively conducted many activities in promoting desert forest plantation with wastewater irrigation throughout Egypt to reduce the wood and timber imports (estimated at LE 3 billion per year). The benefits to the country are numerous. Wastewater irrigation on forests encourages desert land reclamation, conserves the valuable Nile freshwater for food or forage crops, and also, helps urban areas to reduce the burden of increasing sewage waters.

Building on the experience of the pilot forest plantations, MALR agrees with the Agricultural Policy Reform Program to establish a new policy for the Government to sell or lease desert lands adjacent to wastewater treatment plants to private investors for forest plantations. Private sectors can be profited in the business of wastewater safe discharge and reuse in forest plantations.

MALR has a clear policy for the reuse of wastewater effluents: Use the wastewater effluents for irrigating and producing timber trees planted in the desert, and never use the water for irrigating any other crops like fruits, vegetables, and field crops.

The rationale for this policy includes the following:

- Egypt’s timber resources need bolstering, as there are no natural forests in Egypt because of the lack of rainfall (Fig. 5).
- Egypt is currently exporting some fruit and vegetable crops abroad, and the use of effluent water in irrigating such crops would prevent it from competing with neighboring countries producing similar crops.
- While treatments are expected to improve during the coming few years, most sewage water treatment stations in Egypt currently have only primary or secondary treatment facilities. Thus, only in due course and with the availability of new facilities could effluent water be used for purposes such as the production of ornamental plants, cut flowers, and fiber crops.
- Egypt’s current water needs are not critical enough to necessitate use of the effluent water in sensitive crops such as fruits, vegetables, etc.

MALR suggests the following formula for the reuse of wastewater effluents:

WASTE WATER (treated sewage) + WASTE LAND (sandy desert soil) = GREEN TREES (Forest Plantation)

The wastewater-irrigated forest plantation was started in Luxor on 100 feddans of desert sandy soil, right behind the main sewage station of Luxor City. Initially, 40 feddans of the land were planted with the following tree varieties: Eucalyptus, Casuarina, Acacia, Mulberry (Morus Japonica, and Alba), Khaya, and Caprrisus. The area was irrigated with treated sewage water from the nearby treatment station in flood irrigation system [42].

Active pilot wastewater-irrigated forest projects are listed in Table 5 below. These forests were developed in five years, and they are all exclusively irrigated by wastewater effluents.

Table 5 Wastewater-irrigated forest plantation pilot projects in Egypt

Site Names	Area (feddans)	Planted trees	Soils	Irrigation methods
1. Ismalia	500	Caprrisus and Pinus	Desert sandy	Drip
2. Sadat	500	Cuprrisus, Mulberry, and Pinus	Desert sandy	Drip
3. Luxor (close to airport)	1,000 (including a nursery for Mahogany seedlings)	African Mahogany (Khaya)	Desert sandy	Modified flood (a new area uses drip irrigation)
4. Qena	500	Eucalyptus and Mahogany	Desert sandy	Modified flood
5. Edfu	500	African mahogany	Desert sandy	Modified flood
6. New Valley (El Kharga)	800	Eucalyptus, African Mahogany, and Terminalia	Desert sandy	Modified flood
7. New Valley (Paris)	50	African Mahogany	Desert sandy	Modified flood
8. South Sinai	200	Acacia and Eucalyptus	Desert sandy	Drip
9. Abu Rawash	50	Experiment of Neem trees (controlling for insects)	Desert sandy	Modified flood

Source: Appendix 3 [42]

Urban Greenland Irrigation

Wastewater irrigation for urban greenland development is a step towards non-agricultural secondary reuse in cities. Given the heavy agricultural activities in the Delta, the potential for forest development in the Delta is limited. But newly developed cities and towns badly need public parks and street trees to build their green areas. Wastewater effluents should have a great reuse potential for this purpose.

Again, the Ministry of Housing, Utility, and Urban Communities (MHUUC) Decree 44/2000 provides wastewater reuse specifications for park grass, street trees, and other urban green lands to minimize human health risks. There are some kind of cooperation between the Afforestation Department of MALR, and some Governorates, to use wastewater for tree irrigation on highways. This kind of non-crop reuse represents a new way to dispose and absorb urban wastewater in the Delta, and should be encouraged and supported.

Finally there are some priority actions to enhance reuse potential in Egypt as Fahmy [32] mentioned:

- Separation of industrial effluent disposal systems
- Provision of adequate treatment facilities to those communities connected to sewer systems

- Provision of collection stations for the vacuum trucks (rural areas)
- Search for simple low cost treatment technology
- Horizontal expansion based on reuse of treated sewage
- Awareness of the health risks involved with direct or indirect contact with the water

Egypt is now taking a step forward towards future development by reforming the water and wastewater sector. The change concerned institutional and financial aspects. Thus, a Holding Company for Water and Wastewater along with its subsidiary companies was established in 2004 by a presidential decree to develop and implement a holistic policy, which includes expansion of the service delivery, the introduction of modern technology in operations and maintenance as well as management, and increasing the private sector participation in activities which are not core to its mission [20].

Box 3. Egyptian Water Resources
Egypt receives about 98% of its fresh water from the Nile, originating outside its international borders. The availability of fresh water resources in the country is limited mainly to the Nile River, groundwater from both renewable and non-renewable aquifers, limited rainfalls along the northern coast, and flash floods in the Sinai Peninsula. Egypt's share from the Nile is fixed at 55.5 BCM per year by the 1959 agreement with Sudan. The river contributed about 82% of the available water from different resources in the year 2000. It is expected that by the year 2017, it will contribute about 62%. Groundwater is an important source of fresh water in Egypt, both within the Nile system and in the desert. However, ground water occurs at great depths and the aquiferis are generally non-renewable. The renewable groundwater aquifer of the Nile system is recharged from excess irrigation water as well as leakages from the Nile and the distribution network. Current abstraction from the Nile aquifer is about 4.8 BCM/year and is expected to reach 7.5 BCM/year by the year 2017. Groundwater also exists in the non-renewable deep aquifers in the Western Desert and Sinai. The total extraction potential of groundwater is estimated at 3.5 BCM/year. Rainfall is rather negligible as a source of water for agriculture except for a small area along the Mediterranean coast with less than 200 mm/year at Alexandria. It also declines inland to about 25 mm/year near Cairo (Fig. 5). Source: [18].

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Evaluation of the Three Decades of Treated Wastewater Reuse in Tunisia

Faycel Chenini

Abstract Tunisia is one of the developing countries that have developed the use of treated wastewater in irrigated agriculture for more than 30 years. Increase in water demand, as a result of population growth and development plans, is posing serious threats on the existing conventional water resources, including drought impact and stressed water supply with deterioration of water quality. The agricultural sector remains the highest conventional water user with more than 83% consumption. Practically, treated wastewater provides an alternative source of water that can fill an important gap in water deficit for agricultural production and other uses. It represents a strategic option to achieve a higher level of water supply for agriculture and food production and will alleviate the pressure on conventional water resources (Agodzo et al., Use of treated wastewater for irrigation in agriculture: Proposal for a comparative study of Bolivia, Ghana and Tunisia. Wageningen, The Netherlands, 2001).

In 2007, this study was done in the Cap Bon region in the north of Tunisia where most of the TWW reuse was in the irrigated agriculture. There is a high competition between water users' sectors: agriculture, industry, and tourism. This chapter focuses mainly on the evaluation of the regional experience by highlighting the farmers' acceptance and perception of treated wastewater for irrigated agriculture.

In this irrigated area, 100 farmers were interviewed and their farms were visited for observation during the irrigation period. All the farmers were using traditional irrigation method; surface irrigation that leads to considerable loss of water.

This study aims to understand and find out the barriers of the use of treated wastewater in this region considering the high volume of treated wastewater discharged to the sea.

In this region, farmers still confronted more water-scarcity problem. Treated wastewater reuse is common since 1979 because of the increasing water demand,

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the succession of dry season (more than 5 years of drought), and the increasing aquifer salinity.

In spite of this situation, farmers' reluctance to treated wastewater reuse is still presenting a very serious problem. The interesting observation made in this study is that, farmers lack information and knowledge about the need for safe and optimal reuse of this water resource.

During the study of the farming practices, 80% of the farmers said that they are not informed about water quality and 42% said that they are not informed about how to use treated wastewater. Most of them mentioned that they are only informed about the prevention methods such as wearing special shoes and vaccination, about which they were not much interested. Hence, farmers' practices are mainly based on their own experiences, personal perceptions, and points of view.

The key issue here is the emphasis on information and education programs with demonstration areas for any TWW reuse to preserve practitioners' health and environment contamination.

Keywords Farmers, Irrigation, Perception, Reuse, Scarcity of water, Treated wastewater

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Abbreviations

CRDA	Regional Department for Agricultural Development
FAO	Food and Agriculture Organization
Ha	Hectare

INNORPI	National Institute of Standards of Tunisia
JORT	Official Journal of Tunisian Republic
MENA	Middle East and North Africa
NGO	Non-Governmental Organization
NT	Tunisian Standards
RAP	Rapid appraisal process
TND	Tunisian Dinar (1 US$ = 1.37 TND)
TWW	Treated wastewater
WHO	World Health Organization

1 Introduction

Tunisia has built a complex and diversified hydraulic infrastructure all over the country to mobilize and manage more than 95% of all the water resources, and has implemented a management system and a progressive legislation with the aim of answering all social and economic needs.

The issue of sewage techniques and management clearly goes beyond the question of environmental protection and public health. The resource must be recycled in order to maintain a healthy water balance. The Tunisian Ministry of Agriculture wishes to increase the irrigated area without increasing the quantity of water provided. The only way to reach this goal is to extend the irrigated surface by modernized systems and use the alternative solution related to the optimization of treatment and reuse of TWW in irrigated agriculture [7].

The extensive development of irrigated agriculture followed by very low water use efficiency together with the rapid development of urban and rural domestic water supplies seriously depleted conventional water resources. In Tunisia, as in many other developing countries, easily accessible water resources, such as rainwater, rivers, and shallow good quality ground water, are almost depleted. In coastal areas, like Nabeul, water is overused for irrigation and the situation of salt-water intrusion in coastal aquifers has become an important environmental problem [1].

On the other side, owing to irrigation without appropriate planning, drainage and pollution of ground water have emerged as serious and really pressing problems.

The reason for using the treated wastewater in Nabeul was to reduce the impact of salt-water intrusion due to excessive pumping of groundwater. The reuse has enabled citrus orchards to be saved. Effluents were thus reused, mainly during spring and summer, either exclusively or as a complement to groundwater.

However, the reuse of treated wastewater in Tunisia is facing problems; the principal constraints arise within a general framework as follows:

– Great distance of the treatment plant from the available irrigated areas.
– No respect for the standards of the treated wastewater reuse in agriculture.
– Reluctance of farmers because of farming restriction; there is no acceptance of this concept.

- Weak valuation of the majority of the authorized crops to be irrigated by TWW.
- Gap in the knowledge about TWW.
- High salinity of water as well as other problems of a land nature or inherent in the agricultural intensification.
- Insufficient storage capacity of treated wastewater.
- Irregularity of the treated wastewater quality.
- Lack of respect for the Legislation.

Inspite of the water scarcity problems facing irrigation in agriculture, the rate of TWW reuse is still low, and 83% of the total TWW is discharged to the sea [2].

This problem may be due to the integral system including the different actors involved: (1) stakeholders who represent law and legislation of the reuse; (2) institutions responsible for collection, treatment, and distribution; (3) farmers who are the end-users and in direct contact with the treated wastewater; (4) and consumers of the agricultural products.

Farmers are the most concerned actors according to their direct relation with treated wastewater.

The general objective is to study farmers' acceptance or perception toward the reuse of treated wastewater in irrigated agriculture (the current situation) and better understand farmers' knowledge and factors that may influence their reuse at farm level.

2 Rapid Appraisal Process

A Rapid Appraisal Process (RAP) was implemented and was based on farmers' interviews and field observations. In other terms, semi-structured interviews with interface observations were used to get information from the farmers. It consists of face-to-face interviews with some open questions. However, a combination of individual interviews and group interviews was used.

Interviews were held with 100 farmers only. They were taken randomly to proceed with the interviews.

3 Overview of Legislation and Policy Related to TWW

3.1 Legal Aspects

Wastewater use in agriculture is regulated by the 1975 Water Law and by the 1989 decree (JORT, 1989, Decree No. 89-1047). The Water Law prohibits using raw wastewater in agriculture and irrigation of any vegetable that will be eaten raw. The 1989 decree specifically regulates reuse of wastewater in agriculture. Monitoring the quality of TWW for a set of physical and chemical parameters once a month, for trace elements once every 6 months, and for helminth eggs every 2 weeks was planned. As an enforcement of these regulations, using secondary treated effluents is allowed for growing all kinds of crops except vegetables, whether eaten raw or cooked. 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), and a list of crops that can be irrigated have also been set up. The reclaimed water quality criteria for agricultural reuse were developed using the FAO guidelines [3], the WHO guideline (1989) for restricted irrigation (<1 helminth ova per liter), and other Tunisian standards related to irrigation or water supply. Specifications determining the terms and general conditions of reclaimed water reuse as the precautions to be taken to prevent any contamination (workers, residential areas, consumers, etc.) have also been set up.

3.2 Institutional Aspects

The responsibility of collecting wastewater for agricultural purposes is shared by various ministries. The National Sewerage and Sanitation Agency, a subsidiary agency of the Ministry of Environment, is responsible for wastewater collection, treatment, and disposal. The Ministry of Agriculture and water resources is responsible for the implementation of wastewater use projects (mainly the General Directorate for Rural Engineering, and the Regional Departments for Agricultural Development (CRDA) that operate the water distribution system, collect the charges, and supervise the Water Law and other enactment application). The National Research Institute for Agricultural Engineering, Water, and Forestry conducts research on wastewater reuse in agriculture. The Ministry of Public Health is responsible for the regulation of the hygienic quality of reclaimed water reused for irrigation and of marketed crops. At a regional level, the different hygiene departments are in charge of periodical monitoring in their laboratories, health education, and prevention campaigns [4]. The Ministry of Tourism and Handicrafts and the Property Agency for Tourism participate in financing wastewater reuse for irrigation of green areas and landscape (golf courses and hotel gardens). User associations are also involved in wastewater reuse operations. A better coordination among institutions in charge of wastewater reclamation and reuse is required to prevent responsibilities overlapping.

4 Results and Analyses

4.1 Farmers' Acceptance of Treated Wastewater Reuse

The size of land in this area is very small essentially due to successive inheritance. Fifty-five percent of the farmers have a small plot with a size less than 0.5 ha, 40% have an irrigated area between 0.5 and 2 ha, and only 5% of the farmers have more than 2 ha. The land is divided between children and each one takes his part. This is transmitted through generations. This leads to the lack of interest in maintaining farms, especially when the inheritants have another source of income.

Hence, the structure of the exploitation loses its economic character since the majority of the farmers have another source of income and they maintain farms more by habit and tradition than by economic need. People who inherit land from their ancestors do not want to abandon it but they do the minimum necessary to entertain it. In this case we have a familial exploitation.

However, other farmers who live from their irrigated area are interested to get water and to irrigate otherwise they lose their production. Besides this, in the same region there are some areas irrigated with conventional water; so farmers are confronting to the rivalry as they said because the quality of the product is different and then the commercialization of the product will be difficult.

Another point mentioned by farmers during the interviews is the crop restriction. It limits the reuse of TWW by farmers, comparing to other farmers using conventional water; they cannot plant vegetables that are high-income crops.

Regarding the consequences of using TWW on product and production, the general answers were more or less equally divided in their opinions. Indeed, 48% of the farmers said that production decreased and the fruit quality was not good; fruits were tasteless, i.e. not sweet, and the TWW affected plantation, especially the older ones. A lot of them do not consume their products.

On the other hand, 52% of the farmers said that TWW had a positive effect on crops and production, even one of the farmers said “instead of thronging water to the sea, they must give it to us for free, and we need more water.”

Here, we can understand the farmers’ pressing need to irrigate their crops; this situation is essentially because of the droughts over the years. The location and the age of farmers did not influence the farmers’ opinion.

4.2 Farmers’ Practices

During the campaign 2007, the irrigated area of 320 ha was characterized by the following crop pattern: Citrus fruits (190 ha), fodders (110 ha), and industrial crops (20 ha).

The main irrigation method used by all the farmers who were interviewed was surface irrigation; 60% of the farmers were using the furrow irrigation, 25% were using the basin method, and 15% were using both the methods. These methods are traditional and require a good management to reduce water loss. During the field observation, it became obvious that some old farmers were not irrigating in the appropriate way. To maintain the exploitation in optimal vegetation conditions, farmers must take into account many practices and irrigation; fertilization is very important; knowledge about soil fertility and crop requirement is required.

The farmers applied fertilizers as they learned from their experience. Generally, farmers apply manure and a chemical fertilizer essentially based on nitrogen. Farmers did not take into account the fact that TWW contain high quantity of nutrients in spite of their knowledge of this information. One of the farmers interviewed said that when he did not apply chemical fertilizer, he observed that trees lost their leaves. The manure used is essentially based on animal trash. The picture of how farmers use manure and chemical fertilizer is as follows: 45% of the farmers apply only manure, 5% apply only chemical fertilizers, and 50% apply both. It is important to note that 70% of the farmers who use only manure have small plots with a size less than 0.5 ha, only 10% have a land size between 0.5 and 1 ha, and 20% have more than 1 ha. From this picture we conclude that few farmers take into account the nutrient contained in the TWW, and this affects the fertilization costs.

It was observed that quantities of fertilizer and manure are considerably high. Compared to the quantities applied for irrigation with fresh water, farmers do not reduce the amount of fertilizer. For the manure, they apply the same quantities or sometimes more than the dose applied for crops irrigated with fresh water. For them applying manure is beneficial for both crops and soil, so they apply as much as they get manure. Concerning the chemical fertilizer, 12% of farmers are aware that reducing fertilizer is essentially to protect crops and to reduce cost. On the other hand, 78% still apply high quantities of fertilizer and do not consider the nutrients in the TWW.

4.3 Evaluation of the Social Situation

The age of the farmers is one of the parameters that conditioned their behavior. According to the inquiry, 70% of the farmers' ages in the area are between 51 and 85 years, 24% are between 30 and 50, and 6% are less than 30 years; this repartition explains that the users of TWW are mostly old people. This can explain the low level of maintenance in the farms; when people are old they cannot do much hard work and their methods will be limited. This can affect the farm's productivity. The high rate of old people can also lead to the difficulty in accepting a new concept as they have been managing without it for many years. For most of them, it was the only solution to tackle water scarcity; they do not have another choice. Around 70% of the farmers have been using TWW for more than 20 years and this bears ample proof for the increase in water requirement; farmers explain that during their use they did not have any health problems caused by TWW. This can be one of the factors that promote, indirectly, farmers' use of TWW. On the other hand, 15% of the farmers were using TWW for less than 3 years; this shows that using TWW is still continuing to attract farmers.

4.4 Farmers' Perception of TWW Reuse

This study on farmers' attitudes toward the reuse of TWW indicates that farmers are more likely to accept using TWW when awareness of water scarcity, pollution of existing supplies, economic benefit, and water purification exists.

Around 70% of the farmers are using TWW for more than 20 years; meanwhile 20% of them are using TWW from 10 to 20 years and only 10% for a period of 3–10 years.

During the interviews, both short- and long-term health impacts were the most often cited issue regarding the use of TWW; apprehensions about long-term health risks from solvents, pesticides, and other chemicals were also indicated.

Closely related to health impacts are concerns about the reliability of wastewater treatment and water quality.

4.5 Farmers' Preferences

After discussion with many farmers and officials, the reason for using the TWW in the regional 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.

From the interviews, it is learnt that 80% of the farmers prefer to use conventional water if they have the choice. They still consider TWW as a "waste" and even with treatment it still contains pathogens and chemical products that have a dangerous impact on crops. They were also aware about the problem of health hazards. Many farmers were saying that trees, particularly old plantation that have more than 15 years because of the TWW, were dying. Other farmers observed jaundice of the leaves. According to them, any trouble observed in the trees are due to the TWW. Most of these 80 farmers were using water for more than 20 years.

On the other side, only 7% prefer to use TWW. And they said that this water is rich in nutrients and it is beneficial to the crop, and that production with TWW is higher than with conventional water. Farmers who are planting citrus fruits said that trees become more vigorous and production increased considerably. They also said that roots and trunks are capable of filtering and thus the TWW will be filtered by the tree.

In between, 13% of the farmers consider to some extent that TWW is rich in nutrient and that they have to benefit from this but on the other hand, they still consider TWW as not healthy water, and mixing it with fresh water will reduce the negative effects of TWW on crops and soil.

These different points of view pointed out the different mentalities of the farmers but the majority, around 80%, have the same idea. The varied information obtained from interviews show that farmers who prefer TWW were using it for irrigation since 25 years. The age, the nature of the crop, and the volume of water consumed do not have a significant effect on the choice of these farmers to use TWW.

4.6 Farmers' Views on Quality of Water and Treatment

The study shows that 85% of the farmers said that water quality and treatment are not adequate especially in the summer when the wastewater come mainly from tourism sector, as the water will contain more detergents and more chemical products. They also mention the bad odor of water and meant that the water was not treated properly.

At the same time, if there are more tourists this means the volume of water also increases.

The study also shows the difficult situation of the farmers. From one side, they still have a reluctance to use TWW even after more than 20 years of reuse and irrigation practices. They still consider TWW as unclean water with negative effects on their crops. On the other side, farmers need more and more water across the years due to the fresh water scarcity. In this case, farmers do not have the opportunity to choose, and it seems that they are obliged to use TWW.

4.7 Farmers' Awareness Toward Nutrient and Level of Prevention

Around 55% of the interviewed farmers indicated that they knew already that wastewater contained nutrients. They seemed to be convinced of this and they said that plants grow more rapidly with this water, but 20% of them were convinced that in addition to the nutrients this water contained pathogens, chemical products, and detergents which affect both the users and the crops.

Ninety-four percent are aware of and know about nutrients in TWW, among them 38% are aware of pathogens. Only 6% are not aware of TWW.

Taken into consideration that farmers are against using TWW because, as they said, it contain germs, pathogen... etc. However, from interviews it is clear that the knowledge about preventive methods among farmers is not so high; only 46% of the farmers used preventive methods and among them 31% made it properly (making special shoes which are not expensive and they use it for many other practices and doing vaccination yearly). Only 15% were using shoes during irrigation time. Around 54% of farmers did not take preventive steps, they said that the shoes made their feet very hot and it was not comfortable. Some others said that washing after each irrigation was sufficient and they were irrigating for long time without any health problem. They had only problem with their crops.

4.8 View on TWW Impacts on Soils

Farmers were asked if they observed a change in their soils caused by TWW during the whole period of irrigation. Around 60% of them said that there is no difference, soils are the same and even if there are some changes it is essentially due to the drought seasons.

For the farmers who said that there is an effect, only 6% said that they observed positive effects on soils. As they said the soils became stronger and richer in nutrient. Twenty-five percent said that TWW had a negative effect on soils; soils did not retain any more water and nutrients, the water infiltration in the soils become faster, soils become lighter. And 15% mention that they do not have an opinion and they do not know.

In general, Tunisian soils often have low organic contents for high agricultural production. Consequently, there are needs for both water resources development and soil fertility improvement. One way to cope with these problems is to use wastewater in agriculture.

4.9 Information Provided to Farmers

During the interviews, only 22% of the farmers said that they were informed about the water quality, 69% said that they were also informed about the modality of use of the TWW, their main source of information was the association (NGO) through meeting and campaigns of information, but after deep discussion with farmers (when more deep questions were asked) it seemed that the information received was superficial. Even the farmers mention that the main information was about the prevention. On the other hand, 78% of the farmers said that they are not informed about wastewater quality.

4.10 Farmers' Point of Views on Water Price

When farmers were asked about the TWW price, 87% said that the price was proper since 1998, when the prices decreased from 0.058 TND to 0.02 TND/m^3; this means that low prices encourage farmers to use TWW.

Each farmer has his turn to take water, the rotation takes place in the quarter, and it is done by quarter. The irrigation time for each farmer depends on his irrigated area size.

This is the responsibility of the water distribution "aguadi" who open and close every day; the hydrant for the farmers is registered on the list and controls the irrigation time for each farmer.

The public structure, which is in direct relation with the farmer is the water users' association (NGO), represents the source of information of the farmers and at the same time it is the institution that normally solves the farmer's problems.

4.11 Views on Water Availability

With respect to the water availability, 80% of the farmers said water is available and 22% (Majority are big farmers) need more of water and said that the volume of water is not sufficient according to the water flow that is very low comparing to the price that they paid. Their opinion is essentially based on specific situation, which is during the summer period when the water demand increases considerably, and the fact that some farmers were stealing water explains the decrease in the flow of water.

5 Conclusion and Recommendations

It is clear that TWW reuse in irrigation is an attractive option for Tunisia which is struggling with limited water resources. This study pictured farmer's attitudes and wishes with regard to TWW reuse. The general remarks pointed out across this study are that most of the farmers said they worried about the quality of the irrigation water and its health effects on field workers. Farmers also explain their reluctance to use wastewater by the restrictions on the crops they are allowed to cultivate from one side and by the negative effects of the TWW on their existent crops. Also, farmers would like to grow market gardening. Farmers who have exploitation next to other exploitation irrigated with conventional water strongly ask for being provided with conventional water. The price of the TWW did not appear to limit the water use.

The interviews pointed out a lack of information amongst farmers about wastewater quality, health risks related to wastewater reuse, and impacts on crops and soils. Winning the support of farmers should be part of the planning and the management of wastewater use projects [5]. This means more information and more involvement of the farmers in the decision-making process to ensure the success of the projects.

Cultivating food crops, particularly market garden crops, in the vicinity of towns is very attractive. Removing the restrictions on irrigated crops is expected to help farmers moving from rained to irrigated crops. One major obstacle to the wastewater reuse development would thus be overcome. The removal of restrictions demands that two requirements are fulfilled: new regulations should be laid down and effluent disinfection treatments complying with these regulations have to be set up [6].

During this study, we found out some points which can be useful for in-depth study and which show that even with these high numbers (rate of use and irrigated area) there is unwillingness to use TWW on the part of the farmers with a low economic interest to their farms; most of the exploitations have a small size. This research acknowledged that farmer's acceptance hinges on:

1. Farmers' awareness of local water supply problems and perception of the use of TWW as part of a possible solution.
2. Farmers' understanding of the quality of reused water and how it would be used.
3. Confidences in local public utilities.

From the field observation and the interviews with farmers, the point that arises is that farmers are not really aware of the nutrient in the TWW and they do not take this information into account in their practices especially for fertilization. For the contamination, they were to some extent aware of and they think that the treatment quality is not so appropriate.

All the farmers were using surface irrigation, from the field observation, some of them were irrigating in a proper way but many others did not mange their irrigation. What are also observed were the simple tools that farmers use, no specific or calculated timing for irrigation, small-scale operation, and farm size. Thus, there are increasing water losses. This has a direct effect on the pollution of groundwater since TWW contains high rate of nutrients and also pathogens.

Concerning farmers' perception about TWW reuse, the main conclusion was that farmers are still reluctant even after more than 20 years of practices. This reluctance is also observed with young farmers that represent only 6% of the farmers interviewed. Eighty percent of the farmers prefer, if they have the choice, conventional water instead off TWW. A big lack of information concerning water quality and requirement arise from interviews.

In view of all these, the current TWW distribution, disposal, and treatment are low and need more improvements.

This situation is not only due to the farmers but also to the other actors that are involved (policy makers, researchers, stakeholders, and farmers). There is an interdependence of factors that has to be taken into account in integrated water management. Farmers need experimentation and concrete model for them to accept and use new concepts, so for example, enhancing fertilizer efficiency in crop production. Advice on manures involved should be based on model calculation that takes mineralization of organic matter under real production conditions into account.

It is also interesting that all the actors organize and collaborate in order to benefit from the TWW reuse. Organization of the new irrigated areas according to the crop pattern, the nature of the exploitation, and kind of farmers seem to be necessary in the planning of the projects. Organization of the water distribution among farmers and a better management of the irrigation system are also an urgent need to improve TWW reuse. More attention has to be oriented to water quality for irrigation as a means of more control and more respect to the standard norms.

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Wastewater Management Overview in the Occupied Palestinian Territory

S. Samhan, R. Al-Sa'ed, K. Assaf, K. Friese, M. Afferden, R. Muller, W. Tumpling, M. Ghanem, W. Ali, and O. Zimmo

Abstract The Palestinian wastewater treatment sector in Palestine is manifested by inadequate management due to insufficient infrastructure, unsafe disposal of untreated or partially treated effluent and unplanned use of low water quality. The current wastewater treatment plants, established during 1970–1980 under the Israeli occupation, are overloaded and badly maintained with aging equipment, thus posing serious environmental and public health hazards. The challenges behind this unsustainable wastewater sector are exacerbated by the lack of institutional coordination reflected by multiple stakeholder involvement leading to institutional fragmentation and lack of coordination. By law, the Palestinian Water Authority (PWA) is responsible for all regulatory, planning, monitoring, research, and training functions. Despite the current valid Palestinian effluent quality standards, urgent efforts pertaining to effluent monitoring and regulations enforcement are needed. To promote feasible wastewater treatment facilities (WWTFs) crucial strategic regulatory and planning policies were stipulated. Wastewater should be collected, treated, and reused where feasible and the design of WWTFs should be

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modular and community-based with effluent use options. The institutional capacity for implementing and enforcement of water-related rules and regulations should be enhanced. WWTFs including reuse schemes form a key element of an integrated water management strategy with coordinated institutional cooperation. The PWA is committed to sanitation services enhancement in the Palestinian communities to protect public health and the aquatic environment, where the reclaimed effluent must be used for various applications. Effluent reuse practices protect not only the limited water resources, but also enrich the quality and quantity of groundwater and the receiving water bodies; groundwater and surface water.

Keywords Effluent reuse, Palestine, Sanitation, Wastewater, Wastewater treatment

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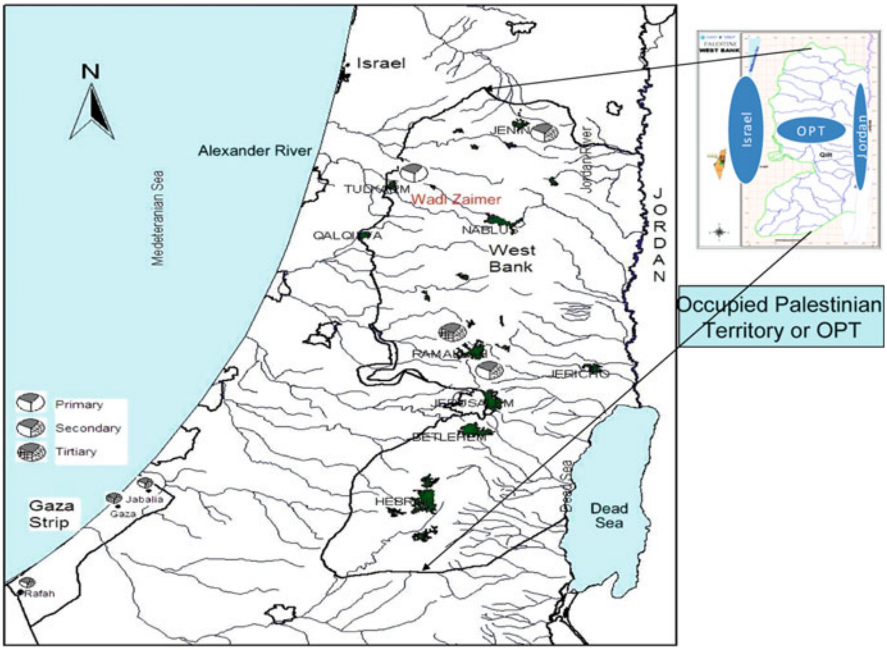
1 Introduction

Palestine (the West Bank and Gaza Strip) is one of the most water-poor countries of the Middle East due to natural and artificial constraints. At present, water needs exceed the available water supply; the gap between water supply and water needs is growing and is calling for the adoption of the integrated water resources management approach and the mobilization of any additional conventional and non-conventional water resources. Treated wastewater is seen as one of the promising solutions that can assist in partially filling the gap of the growing needs for water. The wastewater sector in the West Bank and Gaza (WBG) is characterized by poor sanitation, insufficient treatment of wastewater, unsafe disposal of untreated or partially treated water and the use of untreated wastewater to irrigate edible crops. Currently, only a few treatment plants (Fig. 1) are serving urban centers in the WBG, where most of them were built in the 1970s or 1980s under the Israeli occupation. The majority of the treatment plants are currently overloaded, badly maintained, poorly equipped, and thus represent a serious environmental and public health hazard in urban or rural areas. The reuse of treated wastewater is practiced on a small scale and this option has been generally absent from wastewater treatment plants (WWTPs) after treated or partially treated wastewater [1].

Ramallah wastewater treatment plant (Left) and its effluents (Right) and then to Wadi

Al-Bireh wastewater treatment plant and its effluent (left), and Tulkarem wastewater lagoon (right).

Fig. 1 Wastewater treatment plants in the OPT



Map 1 Location of Palestinian WWTPs and receiving surface water bodies

At present, the Occupied Palestinian Territory (OPT) has eight large urban WWTPs including almost 300 onsite treatment plants (Map 1). These wastewater treatment facilities (WWTFs) serve mainly urban communities covering an approximately 1.5 million population equivalent (PE), where the current total population of the OPT is slightly more than three million. The technology type applied for treatment processes is conventional using the activated sludge system with its process modifications. Most of the existing WWTPs do not function very well, with effluent quality exceeding the prescribed national effluent standards. This is due to overloading, but it can often be the result of the various factors associated with improper physical design, faulty construction and insufficient system maintenance [2, 3].

A recent study made by Al-Sa‘ed [4] revealed that about 20% of the total population that are served by central sewer networks reside in urban communities and the wastewater is discharged into seasonal Wadis (Fig. 2). Among these major Wadis in the West Bank are Wadi Mugata (Jenin district), Wadi Zaimer (Nablus-Tulkarm districts), Wadi Zhor (Qalqilia district), Wadi An-Nar (Hebron district), Wadi Mahbas (Ramallah district), and Wadi Al-Qilt (Jerusalem and Jericho districts). About 33% of the annual collected urban wastewater (73.7 mcm/year) from Palestinian communities is being treated in Israeli WWTPs (Table 1). The treated effluent from this Palestinian wastewater is then even further reclaimed for various applications within Israel (not for the benefit of the OPT), mainly for unrestricted

Fig. 2 Wastewater effluent discharged treated or not treated to Wadis

Table 1 Population served by WWTFs and effluent reuse [4]

Total PE WB & GS (PE)	3,761,646		Annual WW collected	73.70 mcm
Urban PE served (PE)	1,513,214	40%	Annual treated WW	59.5 mcm
Daily sewage collected (m^3)	175,580		Potential WW reuse	81%
Daily WW treated (m^3)	141,748	81%	20 mcm/year are used in Israel	

agricultural irrigation and water for nature purposes, for example, river rehabilitation and landscape recreation [4].

In the OPT areas, most of the existing WWTPs are not functioning well, e.g., the three malfunctioning WWTPs in Jenin, Tulkarem and Ramallah and the non-operating one for Hebron. This is without mentioning the WWTP in the Gaza Strip that is facing the same problems, but more acute, since it has a direct impact on the water resources stored in the fragile geological structure mainly composed of sandstone formations that characterize the area [5]. The wastewater effluent is flowing into small wadis in the OPT (Map 1) and Fig. 2, with the worst situations found in Jabalia, Gaza, and Rafah since their problems are not only the fact that the WWTPs are not functioning well, but the discharge of the effluents and its usage [6].

The conditions of the sewage systems vary, depending on the age and material of the pipes. Approximately 60% of the houses in the urban communities are connected to sewage systems. The connection rate in the major cities varies between 50% in Qalqiliya to 85% in Bethlehem. On the other hand, the wastewater collection system in both Nablus and Hebron are combined systems that collect both wastewater and storm water. Moreover, the situation in the refugee camps can only be classified as very poor as wastewater is channeled into open drains until it flows into either a sewage network in a nearby city or is simply transported to outside the camp boundaries. In most cities, rainwater is allowed to run off on the surface until it eventually reaches the Wadis. Also most of the Israeli settlements in the West Bank have sewage networks and discharge the wastewater into the nearest Wadis on Palestinian lands without any type of treatment or at times partially treated. The purpose of this paper is to assess the wastewater management in the West Bank with special emphasis on wastewater treatment and effluent reuse. Various options for wastewater treatment and reuse have been proposed and investigated in several previous studies. However, few studies have examined the overall picture of wastewater treatment and reuse in the OPT.

This paper will present the wastewater status in the OPT in order to achieve the following objectives:

1. To review the current status of wastewater management in Palestinian communities and the constraining factors behind enhancing the progress of establishing sustainable WWTFs.
2. To present the past Israeli water policies that affect sustainable wastewater management in Palestine and discuss the needs for proper integration for the system to be sustainable.

2 Sanitation Features

The main feature of sanitation in the West Bank is that there are very few sewage collection systems in the rural and suburban areas and therefore very few centralized treatment plants where the effluent is treated. Furthermore, where no collective sewage network is available, each house collects all its sewage in a cesspit with a capacity of 15–25 CM, where they can store the sewage of 1 month. The average water use per inhabitant is between 50 and 80 l per day. A household is made of an average of eight to ten people and these sewage tanks are built close to the house by digging a hole in the ground. They can have concrete walls (septic tanks), or just be earth pools (cesspit) to allow wastewater to infiltrate in the ground. In most cases, cesspits become like septic tanks after a few years. Emptying these pits is done by private tank trucks with a capacity of 5 CM. The evacuation of one sewage tank is a rather heavy operation: the cost of a 5 CM truck is in the 50 NIS range (10€). So the monthly cost of sanitation is in the 200 NIS range (40€ for a typical house in the West Bank) [7]. Al-Sa‘ed [4] made a comparison for the sanitation development in Israel for the period between 1948 and 2008 as presented in Table 2. It is clear that

Table 2 Historical development of sanitation service coverage under various regimes (Israeli occupation period and under the Palestinian Authority rule)

Responsible party	Population served	Years	%Year
Israel (1948–2008)			
Sewerage networks	95%	60	1.6
Centralized WWTPs	90%	60	1.5
OPT-WB (1967–1995)			
Sewerage networks	20%	28	0.7
Centralized WWTPs	5%	28	0.2
Mekorot (Israeli Water Company): 1937		Israeli Water Law 1957	
Palestinian Authority (1995–2008)			
Sewerage networks	+20%	13	1.5
Centralized WWTPs	+76%	13	5.8
Palestinian Water Authority (PWA): 1995		Palestinian Water Law (2002)	

the wastewater management in the OPT was fully neglected during the Israeli occupation period prior to the establishment of the Palestinian Authority in 1995, where only 20% of the total population were served centrally by sewer networks and only 5% of collected sewage experienced physical and partial biological treatment.

The neglect of Israel to provide access to safe sanitation services and the adverse impacts associated with this decision by Israel were recently explored by a World Bank report. This report stated that during the periods of peace and proposed stability conditions the Palestinian Water Authority (PWA) was able to erect only one urban sewage works in Al-Bireh city, with pre-conditions that the nearby Israeli settlements must be connected to the sewage treatment facility [8].

There are three main strategies which the PWA applied in order to promote wide sanitation services coverage and to enhance the performance of current WWTFs in order to comply with national prescribed effluent quality standards, i.e., (a) new erection, (b) retrofitting, and (c) upgrading WWT schemes. Table 3 illustrates the efforts made by the PWA to plan, upgrade and rehabilitate the existing WTPs for municipal wastewater treatment in Palestine. In all the efforts, emphasis was made on integrated pollution control in the upgrading schemes, in which all aspects such as effluent quality standard, sludge disposal, level of technology, upgrading, land availability, maintenance, cost-effectiveness, and other non-financial factors were considered [4].

The challenges facing the sanitation sector are further compounded by the existence of a multitude of governmental and non-governmental institutions involved in the water sector, leading to institutional fragmentation and lack of coordination. Moreover, there is an unclear understanding as to the roles and responsibilities of each institution in the treatment and reuse of wastewater. Today, most of the municipalities are in charge of supplying water and collecting wastewater, but these institutions suffer from limited financial and managerial capacities to perform their functions. In order to achieve a more coherent institutional framework, the PWA is therefore pushing for the establishment of strong

Table 3 PWA efforts made to enhance Palestinian sanitation services [4]

District	Capita(#)	Served (%)	Capita (#)	WW (m3/d)	Treatment system	Year	Status	Activity type
Al-Bireh	50,000	85.8	42.900	4,719	Extended aeration	2000	Operational	Upgraded 2008
Ramallah	35,000	74.6	26.110	2,872	Aerated lagoons	1973	Overloaded	Rehabilitated 2003
Nablus	150,000	82.9	124,350	14,300	Extended aeration	2000	Tendering 09	New WWTP/2020
Hebron	257,000	82.1	210,997	24,265	Conventional ASS	2001	Pending	Hold on
Tulkarem	93,000	68.3	63,519	6,352	Aerated lagoons	1975	Pending	Upgraded 2000
Salfit	25,000	65.6	16,400	1,394	Planned ASS	2000	Pending	No funding
Qalqilia	20,000	70.5	14,100	1,199	No WWTP		Pending	No funding
Jenin	52,000	66.5	34,580	3,458	Aerated lagoons	1972	Pending	Upgraded 1994
Beit Lahia	299,000	68.5	204,845	16,341	Aerated lagoons	1979	Overloaded	
Gaza city	545,000	79.0	430,550	48,243	Parallel TFs/EA	1977	Overloaded	Upgraded/86/98
Rafah	184,000	95.3	175,335	20,000	Aerated lagoons	1978	Overloaded	Upgraded 2008
Bethlehem	84,000	91.2	76,608	8,810	No WWTP		None	
E. Jerusalem	115,000	80.8	92,920	10,686	No WWTP		None	
Khan Yunis	120,000	75.0	90,000	10,350	No WWTP		None	
Total PE	1,710,000		1,513,214	175,580				

regional water utilities which would be responsible for all services, including water supply, wastewater collection, and reuse. The PWA would be responsible for all regulatory, planning and research functions. This institutional arrangement is reflected in the Palestinian Water Law of 2002. Efforts have been made by the PWA to adopt the effluent quality standards of WHO and USEPA, but more needs to be done in terms of monitoring the quality of effluent and the enforcement of regulations. In most of the OPT, there is wide use of individual sanitation systems that treat grey sewage on the plot occupied by the house, and the black sewage is collected in a specific tank. There are a lot of recommendations in a report done by the European Union [7] *as summarized in the following points below*:

2.1 Treatment of the Grey Wastewater

The PHG (Dr. Tamimi interview) case, for instance, consisted of filtration over two successive levels of porous material after storage in a septic tank and a settling phase. We consider this process technically well adapted. *The cost was said to be 2000*€. Moreover, in some cases (the PWEG case) (Munther Hind interview), the treated grey effluent is then used in green houses for drip irrigation of vegetables. This does not need any fertilizer, as the nutriments are already in the treated effluents. *This process brings a substantial income to the household of between 500 NIS (100*€*) and 1500 NIS (300*€*) per month*, which is more than enough to properly maintain the system and pay for the evacuation of the black sewage tank twice a year. Furthermore, ARIJ has developed a compact process (micro-station) treating the grey and black sewage with a reuse of the treated water for the drip irrigation of trees. *This process is expensive, being around 3600*€, and its performance has not been confirmed in the absence of measurements and analyses.

The above described situation has the following impacts on the environment as there are no sewage treatment plants; the wastewater is usually disposed in the nearby wadis, agricultural lands, road sides or on a karstic infiltration area. The raw domestic pollution is heavily disposed into the natural environment and generates heavy infiltration and pollution of springs, wells, and groundwater. Furthermore, the high cost of sewage evacuation for Palestinian families causes them to delay the emptying of their sewage tanks which generates overflows and flooding on the streets or neighboring properties. This causes problems between neighbors and public health threats. On the other hand, the flooding adds their effects to the chronic infiltration generated by cesspits and the many septic tanks which are leaking because of cracks in their concrete walls.

2.2 Type and Size of Collective Sanitation Systems

Most of the processes used are based on a first stage of anaerobic storage of the effluents for 8 days. The pre-treatment is just a simple rack at the entrance of the anaerobic tank. This phase has two goals: to act as a buffer basin and to reduce the BOD value (by around 30%). The BOD concentration is very high in the raw effluents, close to 800 mg/l (only 300 mg/l in France), and due to the low water consumption per inhabitant (50–80 l/day versus 150 in France). The second stage is aerobic, either a bacterial filter or a small gravel filter, the last could be with reed beds. *In all cases, this stage, coming after a long duration anaerobic phase, seemed not enough aerated to allow a significant decrease in the BOD.*

The designers of the sanitation systems could not give us precise performance data of the different structures as there is no effluent quality analysis at the different stages of the process. These processes do not treat nitrogen, which is not a problem as nitrates are rather beneficial for the irrigated crops. Finally, the third phase is a sand bed filtration before sending the treated effluent into the irrigation network [7].

3 Regulatory Framework for Wastewater Reuse

The reuse of treated wastewater often disproportionately benefits the poor. It must be combined with strategies to prevent or mitigate health risks from pathogens, heavy metals, pesticides, and endocrine disrupters and environmental damage from heavy metals and salinity. Long-term institutional coordination among water, agricultural, environmental, and service providers and end users is a requirement for water reuse investments to pay off. Investments in urban water supply and sewerage coverage are raising, however, adequate treatment for agricultural reuse with acceptable risk mitigation for human health and the environment will require further investments.

A guideline to direct the reuse of reclaimed water has been given necessary importance with regard to the associated health and environmental impacts. The first draft for proposed guidelines for effective wastewater management and wastewater reuse in Palestine was prepared by Birzeit University through a MEDA project named efficient Management of Wastewater (EMWTER). This project was a part of a regional project which included Egypt, Jordan, Tunis, and other European countries, where Birzeit University was awarded to implement it at the national level. To this end, a steering committee from different stakeholders (encompassing Ministries such as PWA, EQA, and the Ministry of Agriculture, in addition to Birzeit University and other stakeholders at the community level) was formed to steer the project's progress (www.medawater-rmsu.org and INVENT project (Birzeit University, IWES).[1]

[1]Invent project (Birzeit University – WSI) Efficient management of wastewater treatment – guideline for reuse of treated wastewater.

The Palestinian wastewater and reuse sector strategy calls for adequate institutional capability to manage resources and infrastructure and to regulate wastewater sector activities. This necessarily implies substantial capacity building actions in the areas of wastewater reuse management, operation and maintenance, and development of service utilities. Some of the main current institutional bottlenecks include:

- Lack of adequately trained human resources.
- Unclear designation of responsibilities between stakeholders with a tendency of insufficient delegation.
- Low level of enforcement – due in particular to the insufficient number of inspectors, the lack of monitoring data and equipment, and conflicts in allocation of regulatory responsibilities, plus a culture of producing data without analysis. Legislative change will not have any effect if enforcement is not improved.
- Insufficient awareness of issues related to wastewater.
- Lack of a separation of governance functions from service delivery.

4 Treated Wastewater Quality Standards

The wastewater quality achievable in practice depends on the treatment processes provided at any particular treatment plant and it is essential to match the use of the final water requirements with that level of quality. From the point of view of wastewater reuse in agriculture, however, additional quality characteristics important for health and agronomic reasons are necessary, including bacteria, viruses, helminthes, protozoa, and physical/ chemical parameters such as conductivity and the sodium absorption ratio. Primary treatment of municipal wastewater will remove primarily settled solids together with any adsorbed or entrained materials, such as heavy metals which might be associated with the solids. The effect of primary treatment on health and agronomic parameters is of minor significance, except that there may be a high level of toxic heavy metals accumulated in the sludge. Conventional secondary treatment of sewage in biological filters or activated sludge plants is designed to remove more of the biologically degradable organic material, and typically removes up to 80–90% of the BOD_5 remaining after primary treatment. Again, the health and agronomic parameters are little affected by conventional secondary treatment processes. Further upgrading of secondary effluent is possible in tertiary treatment processes but complex combinations of unit processes are required to achieve a high quality of effluent for unrestricted use in agriculture. Stabilization ponds can achieve high quality effluent standards with low cost, easily operated systems, but the land take is high. In order to meet the need for high quality treated wastewater, new technologies are being developed and studied throughout the world.

4.1 Current Practices of Effluent Disposal into Receiving Water Environment

Almong [9] explored stream restoration and wastewater treatment standards among five main Israeli/Palestinian water[2] challenges and analyzed the actual capability of current Israeli laws and regulatory tools to resolve them. Among the main Israeli water pollution control laws and orders are the following:

– Orders
– Water Law (1959, 1971, 2002, 2004, 2008 and [10])
– Water Commissioner
– Clean Up, Allowing, and Stopping Orders related to water pollution
– Water Council
– Water Drilling Control Law, Drainage and Flood Control Law
– Streams and Springs Authorities Law
– Local Authorities Sewage Law
– Public Health Ordinance
– Licensing of Businesses Law

The 1992 Sewage Effluents Standards (Public Health Ordinance) were set without scientific evidence and were based on European standards assuming a considerable degree of dilution in receiving surface water bodies. The standards unfortunately did not take into consideration the site specific vulnerability of groundwater and the existing water quality of many streams, i.e., that most of these streams have seasonal water flows, if any, or are comprised entirely of wastewater. With almost 95% sewerage coverage, Israel utilizes annually about 300 MCM (75% of treated effluent) in agricultural irrigation and has the status of a "world leader" in reclaimed effluent reuse. The present "20/30" rule for BOD_5 and TSS, respectively, required for effluent discharge into receiving waters and reuse for agricultural irrigation is still effective in health risk reduction. In a recent effort to update the current effluent disposal standards [11] (Table 4) lists selected major parameters highlighting the severe variations between Israeli and Palestinian Standards for Effluent Disposal for agricultural irrigation and discharge into surface water bodies.

Most countries have established national committees and focal points to evaluate and update regulations and standards concerning the quality of effluent used for irrigation or disposal to the water bodies. The development in legislation is not going parallel with the growing needs for wastewater treatment and reuse. Some countries use standards and specifications applied in the most developed countries like those of California, while others modify the WHO guidelines according to their own conditions. There are *Palestinian Standards* for the Treated Wastewater – *PS-742-2003 – and an* industrial effluent discharge Standard *PS-227*–June 1998 which

[2]Palestinian-Israeli Joint Water Committee, 1996–2006, Minutes of Meetings.

Table 4 Israeli and Palestinian standards for effluent disposal in various applications

Parameter	Unit	Israeli Standards 2002		Palestinian standards 2002	
		Unrestricted irrigation	Rivers	Unrestricted irrigation	Rivers
BOD	mg/l	10	10	20	–
TSS	mg/l	10	10	30	
COD	mg/l	100	70		200
Ammonia-N	mg/l	20	1.5	50	5
Total-N	mg/l	20	10		
Total-P/PO_4-P	mg/l	5	0.2	30	5
SO_4	mg/l	–	–	500	1,000
Chloride	mg/l	250	400	500	–
Sodium	mg/l	150	200	200	–
Fecal coliforms	CFU/100 ml	10	200	<200	<1,000
Boron	mg/l	0.4	–	0.7	2
Hydrocarbons	mg/l	–	1	0.002	1
Anionic detergents	mg/l	2	0.5	15	25
Total oil	mg/l	–	1	5	10
pH	[–]	6.5–8.5	7–8.5	6–9	6–9
Dissolved oxygen	mg/l	<0.5	<3	>0.5	>1

have been prepared by a special committee and accredited by the Palestinian Standards Institute.

The Israeli stringent effluent quality standards are being forced upon the Palestinians where the 20/30 rule is required from the Palestinian operators during the first phase of implementation of any new WWTF. However, the WWTPs effluent should comply with the stringent level of standards (10/10) during the second phase of implementation, given a period of 5 years as a construction phase to erect an advanced filtration stage. This is evident from the approval protocol for Tulkarm and Nablus-West WWTPs. The debate over the adequacy of the standards remains controversial as even the less stringent "Inbar Standards" remain debatable, due to the huge financial burdens associated with their implementation and the objections to their adoption by the Ministries of Finance and Interior. Only Al-Bireh sewage works comply with international effluent standards, where local studies revealed that treated effluent is biologically safe for restricted agricultural use [2, 3, 12]. At present, the current valid 20–30 standard is still valid as the level of treatment required for wastewater treatment in Israel. However, before Israel can begin to force new stringent effluent standards on the Palestinian wastewater management facilities, it must first enact those on its own treatment facilities [9, 13].

5 Status of Wastewater Treatment Plants

About 40% (1.5 million) of the total urban population in the OPT have access to central sewer networks, however, only 48% of the total annual collected wastewater is being partially treated (secondary treatment) in Palestinian-owned sewage works, whereas about 33% of the annually collected sewage is being treated within Israel. Under the Status column in the Table 2, it is obvious that the current sewage works are either overloaded or under the "waiting" for Israeli final approval. It is worth while to mention that if a WWTP proposal is technically approved by the JWC, this does not automatically mean direct implementation. The final approval must obey the "military" orders granted by the "Civil" Administration, which takes years to receive-exceeding 10 years for Nablus and Hebron, as examples [4, 8].

Improving WWTP and reuse issues in the West Bank and the Gaza Strip is a high priority because these are highly water-stressed areas and water quality suffers from pollution and over-abstraction. WWTPs are overloaded, so some effluent is discharged without treatment. There is currently some limited interest in wastewater reuse, but it is carried out in an unsustainable manner. The situation has not been helped by the existing weak institutional capacity for wastewater reuse, an incomplete legal framework, very low cost recovery and the continued political conflict. However, rural Palestinian areas in the WBG Strip are subject to serious environmental threats. These threats stem from gaps in the institutional and policy measures available. Therefore, discharge of untreated wastewater, unregulated agricultural practices, and a general lack of infrastructure lead to adverse environmental impacts – such as deterioration of ground and surface water quality. According to EU reports recommendations, the following points should be taken into consideration.

5.1 Maintenance of the Centralized Treatment Plants

This was the most obvious problem, unfortunately. Most of the plants show clearly that there is almost no maintenance which even makes it sometimes difficult to reach the site. The pre-treatment racks are often blocked. The gravel filters feeding is never properly set thereby generating strong preferential pathways for the effluent, which means that some parts of the filtering bed are dry and others overflowed. However, this problem could be easily solved by avoiding the blocking of the pipes and checking the equal flow of the effluents on the filters. When there is a pump in the process (lifting the effluent on a bacterial filter for example) one could wonder about its lifetime and on its maintenance.

5.2 Technical Staff and Training

There is a lack of maintenance because there is no follow up going with these projects. Only investment and implementation costs were considered. A sound technical support would be needed to have a sustainable and properly working system. Even when there is a motivated local technician in charge, which was the case sometimes, he is alone without enough training and without any external support.

5.3 Involvement of the Local Authorities

This is a major condition: the management and the sustainability of the future sanitation service will not be possible without it. This involvement has to be sought from the beginning of the design of the municipal sanitation. The municipality must be an actor when it comes to the choices to be made for this scheme and must contribute to the awareness and information campaign directed toward the population. *The most important point will be to build with the municipality the management rules of the sanitation service, including the tariff policy*. We have noticed that the relatively recent set up of local authorities in Palestine and the current political context has generated certain diversity in the organization of the municipalities and in their ability to manage the sanitation service.

6 Effective Management of Wastewater Across the West Bank and Gaza

The increased population growth rate and rapid expansion of industrial and commercial sites has caused an increased gap between water supply–demand balance, where treated wastewater as an alternative non-conventional water source can help bridge the imbalance. Due to the Israeli occupation in 1967, the Palestinian people have limited access to their land and water resources and are dependant on Israel's prior permissions and foreign donations to establish their water and WWTFs. Currently about 35% of the Palestinian population has access to adequate sanitation, World Bank [8]. On the other hand, there are risks from usage of cesspits and discharge of raw sewage over land or into wadis. Also, delays in project implementation contribute to serious public health and environmental risks, reduce availability of limited water resources as aquifers are polluted by wastewater, and reduce effective treated effluent use in agricultural irrigation, Isaak et al. [14] and Kramer [15]. Furthermore, there are negative impacts on surface water bodies and this can be related to the annual degradation in groundwater quality documented recently by Hareuveni [16].

Regional agencies like CEHA, EU, EC, UNEP, CPP, US AID, GTZ, FAO and others are playing a major role in the adaptation of new regulations and harmonizing existing laws among countries. They also encourage the establishment of regional standards for reuse of wastewater in agriculture, industry or artificial groundwater recharge. They recommend that regional experiences with effluent reuse should be made more widely available for other countries. They also recommend that legislation should be established to advance construction of sewerage systems and treatment of the industrial wastewater before disposal. Finding the proper financial incentives is critical to cover, at a minimum, the operation and maintenance costs of any reuse scheme. Capacity-building, awareness raising and assistance to farmers are also keys to achieving a rational pricing policy and to encouraging farmers to use treated wastewater for crop irrigation. Farmers do not trust the monitoring of water quality carried out in the West Bank and the Gaza Strip and have a preference for reliable, inexpensive and better quality groundwater. However, there are indications that farmers are willing to pay and use treated wastewater for irrigation of crops. In addition to marketing skills training, they need to receive proper information about the impact of treated wastewater on crops. They also need to understand the more severe restrictions on the cultivation of high-value crops with treated wastewater. In addition, a reliable financial structure with cost recovery mechanisms and incentives for farmers to use the treated wastewater is lacking in the WBG. There is no comprehensive pricing policy or prices for reuse in the Palestinian Territory. Currently, farmers do not pay for the reuse of treated wastewater, if any, nor do they pay a penalty for irrigating crops with untreated wastewater [17].

Monitoring the performance of sewage treatment plants in Palestine is the responsibility of the Environmental Quality Authority, Ministry of Health, and the PWA according to their pollution prevention laws. However, all these ministries and entities are lacking a scheduled monitoring program, and neither has a data base. Never the less there is a modest initiative from the PWA main laboratory to build a data base in cooperation with the Al-Bireh Municipality, World Bank [18].

7 Reuse of Treated Wastewater in Irrigation as a Strategic Approach

In the *Palestinian Territories (the West Bank and Gaza)*, the untreated effluent has been used for irrigation of trees and vegetables in an uncontrolled manner. The situation will improve in the future with the heavy involvement of donor agencies and the PWA in reconstructing the whole water supply and sanitation infrastructure. The trend in other countries like Lebanon, Syria, Iran, Iraq, and Yemen is to expand the use of wastewater for irrigation. In Iran, for example, there is about 70 MCM of primary treated effluent that is used for irrigation. The new management reform action related to the water sector considers wastewater as a new source that should be used for irrigation. Artificial recharge of groundwater is another option for reuse of reclaimed wastewater either directly or indirectly. By this, the already over exploited aquifers in the region can be restored. A few cases of artificial recharge have been reported in the region, especially in Oman, Egypt, and Jordan. Recently, PWA in cooperation with PHG (an NGO) was involved in an assessment project to evaluate the potentiality and possibility of this technology taking the existing Beit Lahia WWTP as a pilot. In comparison with other neighboring countries, although Palestine is the less in terms of water consumption, nevertheless the share of treated wastewater in reuse is almost neglected and does not exceed the community level and small WWTP with low cost technologies. Table 3 gives an overview of the quantities of wastewater discharged through the sewerage network and the quantities that are being reused in seven countries. The quantities that are not being reused are directly or indirectly discharged into the sea or evaporate from streams and reservoirs Gearheart et al. [19].

7.1 General Benefits of Wastewater Reuse

The reuse of wastewater reduces the demand on conventional water resources, and thus may postpone investment in a new mobilization of conventional water resources for developing new drinking water supplies. Additionally, the reuse of wastewater reduces the volume of wastewater discharged, resulting in a beneficial impact on the fresh water resources (surface and groundwater), the environment, and public health by protecting receiving areas against pollution. For certain types of reuse, constituents of the wastewater can be used for beneficial purposes such as, for example, nutrients in agriculture.

The situations are contrasted. In some municipalities of Palestine, there was not one farmer reusing treated effluent for irrigation. It was not possible to know if this was related to distrust toward the quality of the effluents (distrust justified taking in account what we mentioned above about maintenance), or if there was no need for this water, or if there was a lack of coordination [20].

During the same period, Al-Khateeb [21] reported some remarkable cases where the choice was made to irrigate fields on slopes. This is surprising owing to the energy cost reasons and the difficulties related to the maintenance of pumps and pipes in this context. Besides, there were land parcels available for gravity irrigation. More generally, it seems that the choice of the location of the treatment sites did not take into account the reuse of the effluents in agriculture in concert with the farmers themselves.

7.1.1 Planning of Wastewater Reuse Projects

Because there are risks associated with the reuse of treated wastewater and sludge in agriculture, any proposed wastewater reuse scheme must be carefully planned and strictly controlled through local and national institutions [21].

7.2 Government Organizations Involved in Treated Wastewater Reuse

The government organizations involved in treated wastewater reuse should be defined and their responsibilities clearly delineated. Status quo in Palestine indicates grand interference among the different institutions, including the NGOs and grass roots representatives. Each institution has developed its own regulations based on its own strategic plans, missions, and goals. EQA insists that all wastewater should be controlled, regulated and managed under its auspices, and at the same time, the MoH underlines that all generated wastewater should be under its responsibility since one of its strategic goals encompasses securing the health of citizens and protecting them from being affected from wastewater-related diseases. PWA insists that all wastewater including its infrastructure should be under its total control and management. Also, this policy is included in PWA's Master Plans, assigning this mission to the wastewater strategic planning department within its organizational structure (Water sector in Palestine – PWA). This is justified based on the acute shortage that the country is facing including the unavailability of conventional water resources to fulfill the actual gap in demand and supply. Treated wastewater should be considered as a viable option to reduce the expected gap if it is addressed to agriculture taking into consideration the huge amount of fresh water consumed by agricultural practices [22, 23].

8 Conclusions

Wastewater treatment and reuse in the OPT of Palestine are still negatively affected by the Israeli military occupation. This practice had resulted in poor capacity building in the water and wastewater sector, limited rural development, poor if not negative economic growth, poor health and sanitation conditions, and physical and environment deterioration. As a result, the Palestinian Authority exists in a complex environment over which it has no control, because it is not officially recognized as the government of a state or a country. The implementation of development projects and plans require many years to be achieved and sometimes they are not achieved at all. There are some answers for wastewater reuse in the OPT, even when taking into consideration the many obstacles which are political, financial, social, institutional, and technical, summarized as follows:

- Technical capacities are not formulated to build on larger-scale reuse projects.
- Effluent reuse is a politically-tied issue with Palestinian water rights, where Israel considers reused wastewater as a part of the total Palestinian fresh water rights, and this calls for Palestinian awareness to wastewater issues.
- Non-availability of sewer networks and proper wastewater treatment systems is eliminating big jumps in reuse practices.
- Reuse standards are still not enforced. Israelis are asking for strict standards, while the Palestinians are not able to manage the presented standards.
- Institutional structure: Efficient financial and technical management of the treatment plants and associated facilities requires strong institutional support.
- Integrated vision: there is no integrated vision developed for the reuse issues; this includes among others political and institutional issues, water policy, and awareness.
- No work permits from the Israelis.
- Lack of funds for collection systems, treatment plants and small scale plants.

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Wastewater Reuse in the Mediterranean Area of Catalonia, Spain: Case Study of Reuse of Tertiary Effluent from a Wastewater Treatment Plant at el Prat de Llobregat (Barcelona)

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Abstract The countries bordering the Mediterranean Sea are under a constant threat of water scarcity due to both natural and anthropogenic factor including highly uneven temporal and spatial distribution of precipitations, growing populations, increasing water demand particularly for agriculture, and the widespread contamination of water resources by a plethora of organic and inorganic contaminants. Unlike most northern European countries with their more temperate and humid climate, in Mediterranean countries a sustainable management of water resources is of vital importance. Wastewater reuse strategies aim at saving valuable freshwater resources and are attractive for a number of applications such as irrigation, increase of the flow of drought-impacted rivers, and artificial groundwater recharge. As an example of the reuse of tertiary treated wastewater, a study was conducted on the impact of its discharge on the loads of emerging pollutants in the lower stretch of the Llobregat River located in the vicinity of the town of Barcelona (NE Spain). The samples were collected in fall of 2008, during a severe drought that took place during the years 2007–2008 in the region. The relative contribution to the loads of the different emerging contaminants of the river upstream and the tertiary treated sewage discharge were estimated based on their respective concentrations and flows. Whereas the contribution of the effluents dominated in case of

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estrogens, river water from the upstream sampling station did so for alkylphenols. Due to their heterogeneous character, the other contaminant families showed a compound-dependent behavior. The calculated loads served to provide an estimate of the overall bulk quantities of the different compounds and families, showing the following rank order: pharmaceuticals > alkylphenols > pesticides > illicit drugs >> estrogens.

Keywords Emerging pollutants, Surface water, Water reuse WWTP, Mass flow balances

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Nomenclature

AC	Activated carbon
AOPs	Advanced oxidation processes
BOD	Biochemical oxygen demand
CA	Clofibric acid
CIP	Ciprofloxacin
CNTs	Carbon nanotubes
COD	Chemical oxygen demand
CP	Cyclophosphamide
CPC	Compound parabolic collector
CWs	Constructed wetlands
DBPs	Disinfection by-products
E3	Estriol
ECs	Emerging contaminants
EDCs	Endocrine disrupting compounds
EfOM	Effluent organic matter
ERMs	Electron-rich organic moieties

GAC	Granular activated carbon
HA	Humic acid
IC50	Inhibitory concentration
ICM	Iodinated X-ray contrast media
LECA	Light expanded clay aggregates
LLE	Liquid–liquid extraction
MBR	Membrane bioreactor
MET	Metronidazole
MF	Microfiltration
MW	Molecular weight
MWCO	Molecular weight cutoff
NF	Nanofiltration
OTC	Oxytetracycline
PAHs	Polycyclic aromatic hydrocarbons
PhACs	Pharmaceutical active compounds
PPCPs	Pharmaceuticals and personal care products
RO	Reverse osmosis
ROSs	Reactive oxygen species
SF	Surface flow
SMT	Sulfamethoxazole
SMX	Sulfamethoxazole
SSFs	Subsurface flow
TOC	Total organic carbon
TSS	Total suspended solids
UF	Ultrafiltration
UV	Ultraviolet
UWTP	Urban wastewater treatment plant
Vis	Visible light
WWTPs	Wastewater treatment plants

1 Introduction

Water is a limited resource and the key to all existing life on earth. After its use in the manifold applications in household and industry, it is generally returned to the water cycle. In the Mediterranean area, the situations or the risks of water shortage are generally ascribable at high level to the growth of demand despite limited renewable water resources – and mainly irregular and unequal qualities – thus with availabilities that rarefy. Mediterranean rivers are characterized by important fluctuations in the flow rates and heavy contamination pressures from extensive urban, industrial, and agricultural activities. This translates to contamination levels in these rivers generally higher than in other larger Mediterranean European basins. Furthermore, under the pressure of water scarcity and the expected increasing occurrence of drought events in the Mediterranean area [1], measures such as

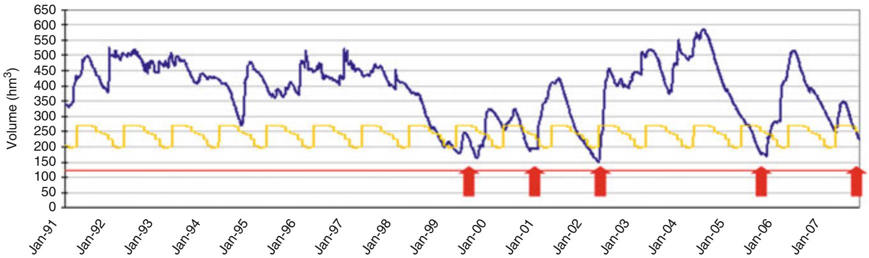


Fig. 1 Evolution of water reserves on the reservoirs of the Ter–Llobregat system, showing drought periods (*upward arrow*)

water reclaim and reuse, addressed to provide alternative resources, are gaining major relevance [2]. Such measures are doubtlessly necessary from the point of view of resource sustainability and are usually promoted by the responsible water authorities.

Catalonia (NE Spain) is one of the regions included in the Mediterranean basin that are among the world areas most suffering from water scarcity. The analyzed trends in Catalonia indicate that water demands are close to available water resources. In spite of uncertainty of estimates, it is likely that available water resources will decrease in the medium and longer term. Episodes of low rainfall will extend in duration, and the frequency of intense rainfall events also will be greater (Fig. 1). Under such panorama of less and worse distributed water, the reuse of treated water is introduced in the national plan of water resource management and is an important part of the criteria of a new environmental policy that promotes a new water culture, trying to increase the nonconventional resources and guaranteeing at the same time the physical, chemical, and bacteriological water quality. For instance, the Llobregat River basin (Catalonia, NE Spain) suffers from extreme and sudden flow fluctuations and receives the effluent discharges of more than 55 WWTPs. At some points, especially in drought periods, the effluents may represent a high percentage of the total flow of the river. Thus, relevant concentrations of organic pollutants are commonly found along the river, usually showing growing levels when moving downstream, due to the corresponding increase of WWTPs discharges and population density [3].

The legal basis for the regulation of the quality standards for reclaimed water for different applications in Spain is established by the Royal Decree [4]. The norm defines the concept of reuse, introduces the regenerated water designation, determines the qualifications necessary to carry out the activity of water reuse and procedures to obtain the demanded concession required by this law, and also defines permitted applications of reclaimed water and quality requirements in each case and compulsory minimum quality criteria for the use of the regenerated waters according to uses. Whereas the said Decree covers microbiological and general physicochemical aspects, the so-called emerging microcontaminants are currently ignored from the regulatory point of view.

2 Water Reuse in Catalonia

The Catalan Water Reuse Program (PRAC) that is currently in process is set within the regulatory context of the Hydrological Plan for the Inland Basins of Catalonia, in addition to the Wastewater Treatment Plan, and will form part of the Catalan River Basin District Management Plan. Table 1 shows the planned management measures to increase water resources.

Reuse of treated water is promoted and incorporated into integrated resource planning, known as direct or planned reuse of reclaimed water, and is viewed as an alternative source of the resource for uses that do not involve drinking water (industrial uses, watering golf courses, municipal uses, agricultural irrigation, aquifer recharge). Water treated at wastewater treatment plants (WWTPs) and then through further additional or complementary processes in connection with reclamation has the sanitary and physicochemical quality required for certain uses.

In Catalonia, the entry into force of Directive 91/271/EEC on the treatment of urban waste water and its transposition to national legislation provided for the implementation of a set of sanitation systems that contribute to improving environmental quality of the receiving environment. Programs of Urban Wastewater Treatment (PSARU) have implemented this policy and have given rise as main output to the construction of more than 300 treatment plants, currently dealing with a volume of 665 hm^3 of water annually. Of this total volume treated, the year 2008 was reused in Catalonia a volume of almost 51 hm^3, i.e., 7.6%. In summer, this percentage reaches nearly 12% in the month of July, when water needs are higher. Figure 2 shows the distribution of reused volumes. In addition, about 270 hm^3 per year are incorporated into streams, where they can be indirectly reused downstream.

In the program it is expected to reach 229 hm^3 per year of water treated with the subsequent production (excluding waste) of 204 hm^3 per year of reclaimed water. If one considers that the PSARU foresees that on the horizon 2015, in Catalonia a total volume of 720 hm^3 per year of wastewater will be treated; this means that 31% of the total flow will be processed on reclamation facilities. This volume of reused water will be achieved as a sum of three components: reuse already in service, an

Table 1 Planned management measures in Catalonia to increase water resources

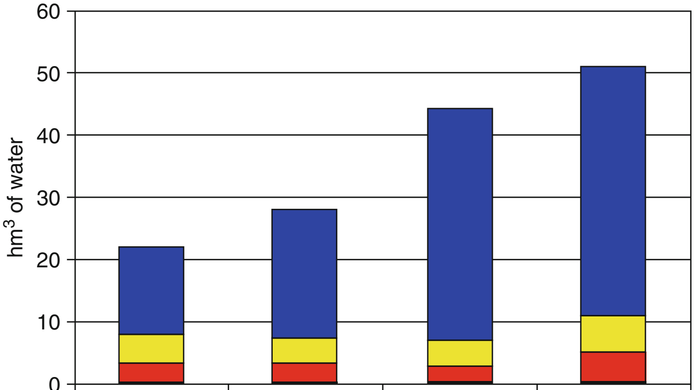
Management measure		hm^3 per year
New resources	Desalination	190 (80)
	Reuse	101[a] (51)
	Groundwater recharge and recovery	43
Infrastructure improvement	Improvement of water treatment, regulation, and systems	55
Total increase (by 2025)		389

Source: Catalan Water Agency (ACA), 2009

The amount already achieved in 2009 is in parentheses

[a]Only flows discharged to the sea are computed as new resources

ever-increasing utilization of existing reuse facilities and, finally, entry into service of new facilities under this program. Figure 3 shows the distribution of uses: the most important is agriculture with 45.7 hm^3 (30%), followed by industrial use with 39.7 hm^3 (26%), the environmental use with 38.6 hm^3 (25%), municipal use with 18.5 hm^3 (12%), and finally recreational use with about 10 hm^3 (7%).



Year	2005	2006	2007	2008
Environment	14.1	20.4	37	40
Leisure	4.7	4.5	4.6	5.8
Agriculture	2.9	2.8	2.2	4.7
Municipal	0.4	0.3	0.5	0.5

Fig. 2 Evolution of volume of reused water by use (hm^3) from 2005 to 2008

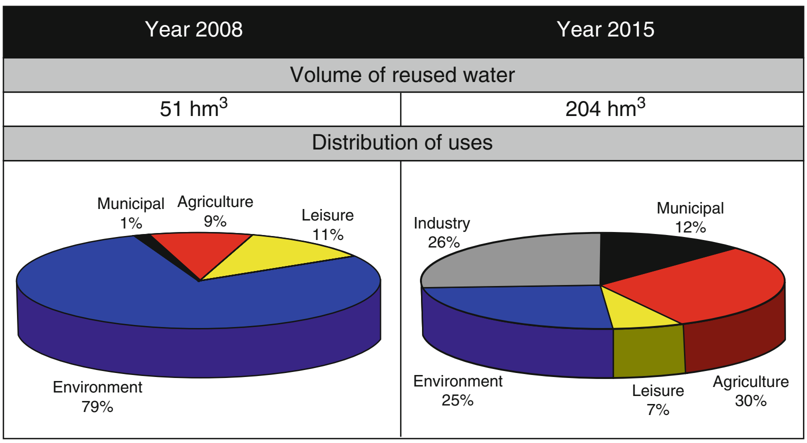


Fig. 3 Current and planned reuse of water in Catalonia

3 Treatment Requirements for Water Reuse

3.1 Tertiary Treatments in Catalonia

After the secondary settling of the activated sludge treatment, tertiary treatments are being implemented in conventional WWTP with the objective of producing water with sanitary and physicochemical quality that allow for specific reuse. As such, it is an activity that should be promoted and incorporated into an integrated resource planning, known as direct or planned reuse of reclaimed water. In 2010, 42 of 89 catalan WWTP are operated with tertiary treatments (Fig. 4). Two types of tertiary treatment are usually applied in the Catalan WWTP depending on the end use of the water. The basic treatment encompasses coagulation, flocculation, filtration, UV disinfection, post (additional) disinfection, and oxygen saturation. The advanced one includes treatment by ultrafiltration and reverse osmosis [5]. For instance, the water reclamation station "El Prat," located in the metropolitan area of the city of Barcelona, provides water for different purposes. After the basic treatment, the water can be used for irrigation of agricultural land as well as for golf courses in the surroundings but also for industrial use. Furthermore, part of the treated wastewater is returned to the river to maintain the water level and ensure an increased flow. At the same time, a part of the treated wastewater is directed to a reverse osmosis plant (advanced treatment) for further treatment, and the water is pumped into the underground to avoid salt water from the sea to seep into the groundwater resources.

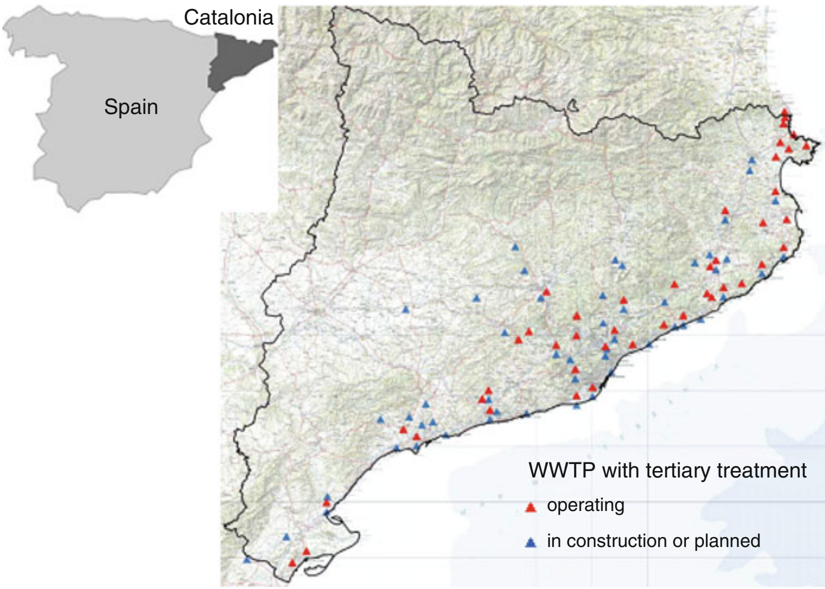


Fig. 4 Wastewater treatment plants (WWTPs) in Catalonia with tertiary treatment (ACA 2010)

3.2 Tertiary Treatments in the WWTPs for Xenobiotic Micropollutants Elimination

Wastewater treatment has continuously been considered to fulfill the increasing requirements on the quality of the final effluents in the last several years. As a precious natural resource, freshwater is a critical condition of economic development and essential life in many countries. Furthermore, unplanned indirect potable reuse of municipal wastewater is a common practice all over the world [6]. However, concerning pollutants, which include conventional and emerging contaminants, monitoring studies on their occurrence in surface water or wastewater are published more and more in recent years [7]. To minimize the environmental impact of these pollutants in urban wastewater, more efficient and safe wastewater treatments are required.

Most of the WWTPs are based on a three-stage process consisting of preliminary sedimentation and microbiological processes combined sometimes with tertiary treatment (Fig. 5). The removal of conventional wastewater parameters [biochemical and chemical oxygen demand (BOD and COD), total suspended solids (TSS), and nutrients] in wastewater has been an object of extensive research [9]. But current technologies for urban wastewater processing are still far from being completely satisfactory, and the total organic carbon [10] of the effluents after wastewater treatment is still much higher than the typical values from fresh natural waters [11]. In secondary effluents, a variety of conventional and specific contaminants, such as pharmaceuticals and personal care products (PPCPs) and endocrine disrupting compounds (EDCs), have been detected in effluents from a variety of WWTPs in a wide range concentration [12–16]. The most frequently detected micropollutants in effluent of WWTPs around the world are listed in Table 2.

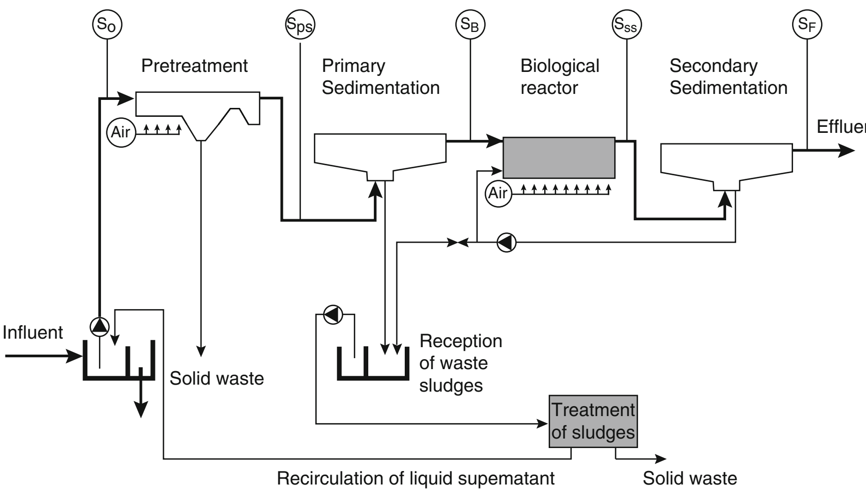


Fig. 5 Example of diagram of the municipal sewage treatment plant [8]

Table 2 Occurrence of representative xenobiotic micropollutants in secondary effluent wastewaters in WWTPs

Compounds	Concentration	Frequency[a]	Country	References
Ketoprofen	<0.89–1.53	73	Spain	[17]
	38.0		Korea	[18]
	<LOD–1,500.0		Spain	[19]
Naproxen	0.72–2.64	87	Spain	[17]
	650–4,800		Spain	[8]
	220.0–4,280.0		Spain	[19]
	128.0		Korea	[18]
	90–105		Korea	[20]
Ibuprofen	0.83–7.48	93	Spain	[17]
	200–5,800		Spain	[8]
	0.78–48.24		Spain	[19]
Diclofenac	<0.36–0.91	85	Spain	[17]
	23.0		Korea	[18]
	8–2,349		Germany, Japan, E.S.U.W.[b]	[21]
	90–350		Korea	[20]
Iopromide	6,600–9,300	57	Spain	[8]
Indomethacine	46–124	–	England	[21]
Acebutolol	35–255	–	Finland	[22]
Atenolol	40–1,180	100	Finland	[22]
	30–220		Korea	[20]
Propranolol	16–135	100	England	[21]
	32–77		USA	[23]
	16–388		E.S.U.W.	[21]
Metoprolol	280–1,600	97	Finland	[22]
	60–108		China	[24]
Sotalol	130–1,120	n.m.	Finland	[22]
Carbamazepine	290–2,440	100	Finland	[22]
	178		Korea	[18]
	69–120		China	[24]
	34–3,117		E.S.U.W.	[21]
	<LOD–1290		Spain	[19]
	350–900		Korea	[20]
Acetylsalicylic acid	18	–	Korea	[18]
Clofibric acid	21	55	Korea	[18]
Salicylic acid	2–3	45	Spain	[17]
Mefenamic acid	34	–	Korea	[18]
Cyproconazole	169	–	Greece	[25]
Penconazole	22	–	Greece	[25]
Triadimefon	8	–	Greece	[25]
Pyrimethanil	191	–	Greece	[25]
Tebuconazole	6–338	–	France, Germany, Greece	[25]
Erythromycin	216–2,054	100	China	[26]
Erythromycin-H_2O	132	50	Korea	[18]
Roxithromycin	35–278	100	China	[26]
	85		Korea	[18]
Lincomycin	147	–	Korea	[18]
Sulfamethoxazole	n.m.–580	73	Spain	[8]
	9–78		China	[26]
	8–2,200		Canada, E.S.U.W.	[21]
	30–60		Korea	[20]

(*continued*)

Table 2 (continued)

Compounds	Concentration	Frequency[a]	Country	References
Ciprofloxacin	n.m.–130	91	Spain	[22]
Norfloxacin	n.m.–110	100	Finland	[22]
	27–85		China	[26]
Ofloxacin	n.m.–30	n.m.	Finland	[22]
Estrone	n.m.–4,400	93	Spain	[8]
	1–96		Canada	[27]
	n.m.–47		D.E.F.[c]	[28]
17β-Estradiol	<LOQ–3,000	74	Spain	[8]
	0.2–15		Canada	[27]
	n.m.–15		D.E.F.	[28]
17α-Estradiol	<0.1–5	64	Netherlands	[28]
Estriol	n.m.–21	92	D.E.F.	[28]
17α-Ethinylestradiol	n.m.–12	59	D.E.F.	[28]
Caffeine	24	–	Korea	[18]
	150–3,010		Spain	[19]
Galaxolide	0.5–45,400	100	Spain	[8]
Tonalide	0.1–14,780	100	Spain	[8]

n.m. not measured
[a]Frequency of quantification in effluent
[b]E.S.U.W. England, Sweden, USA, and Wales
[c]D.E.F. Denmark, England, France, Netherlands, Sweden, Germany, Italy, Spain, Japan, Canada, and USA

These specific contaminants can go through the WWTP without undergoing a complete elimination, and some of them will form part of the organic matter present in the effluents of urban wastewater treatment plant (UWTP) [11, 29, 30]. Previous studies indicate that most of the removal of micropollutants during primary and secondary treatment is likely to be predominantly due to sludge/solid phase adsorption, with only minor contributions to the water phase [31]. As a pervasive problem, PPCPs contamination has recently gained widespread public attention, and they may have severe impacts on the environment. From a view of precaution principle, options that can deal with pharmaceuticals in municipal wastewater treatment should be prepared [32]. Many studies have shown that conventional wastewater treatment methods such as activated sludge processes are not effective for eliminating pharmaceuticals [22, 25, 33]. Therefore, there is currently a focus on the potential of tertiary treatment technologies as a polishing step to eliminate a wide range of contaminants.

It is well known that the complete elimination of micropollutants in secondary effluents is a real challenge for wastewater engineers. Removal of drugs from wastewater may range from 0% to 100% depending on the drug and the treatment process, even for the same compound, further complicating prediction of environmental concentrations [34]. In addition, new compounds are continually being manufactured and released to the environment. Many research efforts have been put in the development of wastewater treatment technologies to decrease the concentration of pharmaceuticals [35]. Numerous papers address the oxidative removal of micropollutants from municipal wastewater with ferrate [36], ozone

Table 3 Redox potentials for the oxidants/disinfectants used in water treatment

AOPs	Reaction	E^0 (V)
Ferrate (VI)	$FeO_4^{2-} + 8H^+ + 3e^- \Leftrightarrow Fe^{3+} + 4H_2O$	2.20
	$FeO_4^{2-} + 4H_2O + 3e^- \Leftrightarrow Fe(OH)_3 + 5OH^-$	0.70
Ozone	$O_3 + 2H^+ + 2e^- \Leftrightarrow O_2 + H_2O$	2.08
	$O_3 + H_2O + 2e^- \Leftrightarrow O_2 + 2OH^-$	1.24
Hypochlorite	$HClO^- + H^+ + 2e^- \Leftrightarrow Cl^- + H_2O$	1.48
	$ClO^- + H_2O + 2e^- \Leftrightarrow Cl^- + 2OH^-$	0.84
Chlorine	$Cl_2(g) + 2e^- \Leftrightarrow 2Cl^-$	1.36
Chlorine dioxide	$ClO_2(aq) + e^- \Leftrightarrow ClO_2^-$	0.95
Fenton's reagent	$Fe^{2+} + H_2O_2 \rightarrow Fe^{3+} + OH^- + \bullet OH$	–
	$Fe^{2+} + \bullet OH \rightarrow Fe^{3+} + OH^-$	–
	$Fe^{3+} + H_2O \rightarrow Fe^{2+} + \bullet OH + H^+$	–

Date from [36, 42, 43]

[37, 38], chlorine dioxide [35, 39], advanced oxidation processes (AOPs), such as ultraviolet (UV) combined with H_2O_2 [40, 41], photo-Fenton [42, 43], electro-oxidation [44], and nonthermal plasma [45]. Because of the high potential of oxidants (Table 3), the effective elimination of a large number of micropollutants in WWTPs is easily achieved. High-pressure driven membranes such as a nanofiltration (NF) membrane and a reverse osmosis (RO) membrane are considered to be effective options for removal of pharmaceuticals [46]. Other options such as constructed wetlands [47] are designed as extra treatment to remove potential hazards, and those that do are specific to subsurface flow constructed wetlands (SSFCWs) [48]. In addition, mitigation of micropollutants may occur during sand/carbon filtration and adsorption [49, 50] or in biological Fenton-like processes [51]. Finally, these novel technologies are applied to enhance the removal of nitrogen, phosphorus, and xenobiotic micropollutants. However, these processes are extremely expensive as tertiary treatments, especially AOPs [52]. The need for cost-effective, sustainable, and efficient tertiary treatment for the elimination of xenobiotic micropollutants released by secondary effluents is highlighted recently.

Each technology is one development that may play an increasing important role in tertiary treatment for xenobiotic micropollutants elimination. Therefore, finding an efficient method to remove micropollutants in municipal wastewater should base on the characterization and efficiency of these technologies which are assessed in previous literatures.

3.2.1 Applicable Tertiary Treatment Options to Eliminate Xenobiotic Micropollutants

Constructed Wetlands

Among the tertiary processes in WWTPs, wetlands and ecosystem services as a low cost and sustainable options attract many interests in the engineered use. Constructed wetlands are kinds of engineered wetlands which use vegetation, soil, and microbial assemblages to treat, at least partially, in eliminating pollutants. Constructed wetlands have many applications, ranging from the secondary treatment of domestic, agricultural, and industrial wastewater to the tertiary treatment. On a global scale, people have used it for pollution control, creation, restoration, or enhancement of habitats for centuries [53–55]. It is a widespread technology for polishing treatment of wastewater from municipal, industrial, and agricultural water sources. In addition, the number of papers on constructed wetlands has been increasing up to 194 per year from 1980 to July 2008 [55]. In the past, most of the studies have been conducted to assess their removal efficiency of conventional pollutants such as BOD, COD, TSS, and nutrients. However, wetlands are exposed to a wide range of pollutants in varying loads, and less research studies focus on the elimination of a wide range of micropollutants such as PPCPs [56]. In recent years, the applicability of constructed wetland as a cost-effective and operational alternative in tertiary treatment for the elimination of various contaminants has been explored [48].

Table 4 describes the removal rates of micropollutants in various tertiary treatment processes. An engineered constructed wetland connected to both a WWTP and a river is investigated for elimination of nine different organic micropollutants, including pharmaceuticals, endocrine disruptors, and personal care products [20]. Atenolol, naproxen, and triclosan are observed with high removal efficiencies, but other compounds exhibit medium-range and fluctuating (or somewhat low) removal behaviors. The relative important of a particular process can vary significantly; appropriate design and operation parameters are preliminary requirements.

Surface flow constructed wetlands (SFCWs) might provide an alternative technology for the attenuation of PPCPs, which does not neglect the recovery function of the wetlands [47]. Moreover, the SFCWs show removal efficiencies higher than 90% for 12 pollutants, including PPCPs and herbicides [58]. Vertical-flow constructed wetlands are reported to get the highest removal efficiency of 67.8 ± 28.0%, 84.0 ± 15.4%, and 75.3 ± 17.6% for E1, E2, and EE2, respectively [57]. Three polycyclic aromatic hydrocarbons (PAHs) of fluoranthene, pyrene, and benzo(k)fluoranthene from two types of PAH-contaminated effluents were investigated using vertical flow constructed wetlands [83]. Microcosm constructed wetlands systems which establish with a matrix of light expanded clay aggregates (LECA) and plants are evaluated for its ability to remove pharmaceuticals ibuprofen, carbamazepine, and clofibric acid from wastewaters in previous study [60]. Furthermore, a pilot-scale ponded wetland is also studied as a potential management practices for the reduction of pesticide in agricultural runoff [59]. The real-scale hybrid pond–CW systems (ponds, SFCWs, and horizontal SSFs) connected in series are studied in the PPCPs removal mainly exceeding 70% [17].

Other similar treatments of biologically activated soil filters are very similar in principle to SSFs. The elimination rate with low hydraulic load (61 L m^{-2} per day, water retention time: 2 days) are higher than 96% [84].

Therefore, the previous studies may support improved testing and better optimization of different kinds of wetlands designs and operational modes. The application

Table 4 Removal rates of micropollutants (as a percentage) in tertiary treatment processes

Tertiary treatment	Compounds	Parameters and conditions	Matrix	Removal (%)	References
Wetlands					
Hybrid pond-constructed wetlands	Analgesic and antiepileptic drugs, and fragrances	Fresno de la Vega, flow rate: 3,200 m^3 per day; Cubillas de los Oteros, flow rate: 20 m^3 per day; Bustillo de Cea, flow rate: 56.3 m^3 per day	Domestic WW[a] effluent	Ketoprofen: 77–81; Naproxen: 73–85; Ibuprofen: 42–99; Diclofenac: 65–87; Salicylic acid: 93–97; Caffeine: 83–96; Methyl dihydrojasmonate: 81–97	[17]
Constructed wetlands	9 Pharmaceuticals	Hydraulic retention: 6 h; flow rate: 1,800 m^3 per day; width: 30 m; length: 120 m; depth: 0.13 m	Effluent of WWTP	Sulfamethoxazole: 30–50; Atenolol: 95–100; Dilantin: 5–40; Carbamazepine: −10 to 60; Diazepam: <5; Diclofenac: 30–80; Naproxen: 70–80; Triclosan: 60–100	[20]
Vertical-flow wetlands	3 Estrogens	Three wetlands named ES (extremely shallow), S (shallow) and CD (common depth); average total influent flow: 8,100 m^3 per day; surface area of each wetland: 0.15 m^2	STW[b] effluent	Estrone: 68 ± 28; 17β-Estradiol: 84 ± 15; 17α-Ethynylestradiol: 75 ± 18	[57]
Surface flow constructed wetland	PPCPs and herbicides	Average influent flow rate: 23,700 m^3 per day; surface area: 1 ha; hydraulic retention time: around 1 month	Secondary effluent of the WWTP	Ibuprofen: 95–96; Naproxen: 52–92; Diclofenac: 73–96; Ketoprofen: 97–99; Clofibric acid: 32–36; Carbamazepine: 30–47; Flunixin: 64; Galaxolide: 85–88; Tonalide: 88–90; Mecoprop: 79–91; MCPA[c]: 79–93; Terbutylazine: 1–80	[58]
Mixed open/vegetated constructed wetlands	3 pesticides	Pilot-scale; open pond surface area: 100 m^2, deep: 1 m; vegetated pond surface area: 200 m^2, deep: 0.5 m	Irrigation water	Endosulfan: 5–42; Fluometuron: 32–48; DDE: 18–56	[59]

(*continued*)

Table 4 (continued)

Tertiary treatment	Compounds	Parameters and conditions	Matrix	Removal (%)	References
Microcosm constructed wetlands	3 pharmaceuticals	Each microcosm length: 0.6 m, width: 0.5 m; deep: 0.4 m	WWTP effluent	Clofibric acid: 88–97; Carbamazepine: 48–75; Ibuprofen: 82–96	[60]
Surface flow constructed wetlands	8 PPCPs	Single cell system, length: 189 m, width: 53 m; planted with 2,250 transplant units of *Phragmites australis* and *Typha latifolia*	Effluent of urban WWTP	Ibuprofen: 96; Naproxen: 72; Diclofenac: 85; Ketoprofen: 98; Clofibric acid: 34; Carbamazepine: 39; Galaxolide: 87; Tonalide: 89	[47]
Membrane technologies					
Nanofiltration (NF) and reverse osmosis (RO) membranes	1 pharmaceutical	Effective membrane area: 3.52×10^{-3} m^2, total effective volume: 400 mL; trans-membrane pressure: 5×10^5–25×10^5 Pa; pure water permeability: 5.8 L m^{-2} h^{-1} bar^{-1} (NF); 4.0 L m^{-2} h^{-1} bar^{-1} (RO)	Ultrapure water and effluent of WWTP	Cyclophosphamide in Milli-Q water: 20–40 (NF), 93–97 (RO); in effluent WW: 60 (NF), 92–97 (RO)	[61]
Ultrafiltration (UF) and NF membranes	28 pharmaceuticals	Cross-flow mode; effective area: 28 cm^2; volume of pressurized storage vessel: 500 cm^3	Secondary effluent of municipal WWTP	4-AA[d]: 81–89; Antipyrine: 54–82; Atenolol: 11–76; Benzafibrate: 70–91; Carbamazepine: 56–81; Ciprofloxacin: 65; Codeine: 79–94; Diclofenac: 71–92: Fenofibric acid: 86–88; Furosemide: 70–78; Gemfibrozil: 59–85; Hydrochlorothiazide: 44–56; Ibuprofen: 69–88; Iopamidol: 64; Iopromide: 86; Ketoprofen: 58–87; Metronidazole: 73–81; 4-AAA[e]: 81–88; Naproxen: 47–80; 4-FAA[f]: 51–87; Nicotine: 60–81; Ofloxacin: 95; Pravastatin: 73–95; Primidone: 25–72;	[62]

				Ranitidine: 28–75; Sulfamethoxazole: 87–95; Trimethoprim: 74–86; Velafaxime: 45–87	
NF/RO membranes	EDCs and pharmaceuticals	Full-scale; treat ability: 720 $m^3\ h^{-1}$; permeate flow: 356.4 $m^3\ s^{-1}$ (RO), 234 $m^3\ s^{-1}$ (NF)	Groundwater	Hydrochlorothiazide: 90 (NF), >90 (RO); Ketoprofen: >95 (NF), Gemfibrozil: >50 (NF), 50–90 (RO); Diclofenac: 100 (NF), 100 (RO); Acetaminophen: >40 (NF), 60–85 (RO); Sotalol: 100 (NF), 90–100 (RO); Sulfamethoxazole: >90 (NF), 100 (RO); Metoprolol: >95 (NF), 80–100 (RO); Propyphenazone: >95 (NF), 90–99 (RO); Carbamazepine: >97 (NF), 98–100 (RO); Mefenamic acid: 30 (NF), 45–70 (RO); Glibenclamide: >82 (NF), >80 (RO)	[63]
NF membranes	Hormones and antibiotics	Active membrane area: 14.6 cm^2; molecular weight cutoff: 200–300 Da	Synthetic solutions	Estrone: 80–100; Estradiol: 65–100; Testosterone: 60–95; Sulfamethaxazole: 35–100; Sulfathiazole: 90–100; Tetracycline: 95–100; Oxytetracycline: 92–100	[64]
NF/RO membranes	Steroid hormone	Four NF/RO membranes; maximum pressure: 4,137 kPa; maximum flow: 20 L min^{-1}	Treated sewage effluent	Rejection decreases with the time	[65]
AOPs-ozone					
Ozone	Amoxicillin	Flow rate of ozonized oxygen: 36 L h^{-1}; pH: 5.5; $k_{OH,\ AM} = 3.93 \times 10^9\ M^{-1}\ s^{-1}$	Effluents from sewage treatment plants	>90	[66]
Ozone/catalysts	Ciprofloxacin	Concentration of ozone generated: 2,500 ppm_v in dry air; mass transfer coefficient: $k_L\alpha = 5.5\ h^{-1}$; pH = 10	Effluent of hospital WWTP	>95	[67]

(*continued*)

Table 4 (continued)

Tertiary treatment	Compounds	Parameters and conditions	Matrix	Removal (%)	References
Ozone	Clarithromycin	Concentration of ozone: 3×10^{-4} M; pH = 7; $k = 4 \times 10^{4}$ M^{-1} s^{-1}	Effluent of WWTP	100	[68]
Ozone, Ozone/ H_2O_2	PPCPs	Mixture of ozone and oxygen with a concentration of ozone: 45.9 g Nm^{-3}	Effluents from sewage treatment plant	More than 80 emerging compounds studied; removal of 100 compounds are: 4-AAA; 4-FAA; Atenolol; 4-MAA; Antipyrine; Bezafibrate; Carbamazepine; Carbamazepine; Epoxide; Celestolide; Codeine; Diazepam; Diclofenac; Diuron; Erythromycin; Fluoxetine; Furosemide; Gemfibrozil; Hydrochlorothiazide; Indomethacine; Ketoprofen; Ketorolac; Mefenamic Acid; Mepivacaine; Metoprolol; Metronidazole; Naproxen; Ofloxacin; Omeprazole; Paraxanthine; Propanolol hydrochloride; Ranitidine; Salbutamol; Sotalol; Sulfamethoxazole; Traseolide; Trimethoprim;	[69–71]
Ozone	72 Parmaceuticals	5-L glass jacketed reator; concentration of ozone: 9.7 g Nm^{-3}; gas flow: 0.36 Nm^3 h^{-1}; mass transfer coefficient: $k_L\alpha = 0.010 \pm 0.005$ s^{-1}	Effluent from sewage treatment plant	More than 70% compounds are completely removed	[72]
UV radiation					
UV, UV/H_2O_2	4 Pharmaceuticals	Low-pressure UV lamp; photolysis quantum yields: 6.32×10^{-2}–2.79×10^{-1} mol E^{-1};	Simulated water	Ibuprofen: >40; Diphenhydramine: >25; Phenazone: 40; Phenytoin: 30	[73]

		$\lambda = 254$ nm; solution pH = 7;			
UV	Propranolol (PRO) and metronidazole (MET)	UV-254 mercury lamp and UV-365 black light mercury lamp	Simulated water	Time based rate constants: 4×10^{-2} (PRO); 26×10^{-2} (MET)	[74]
UV/TiO_2, UV/H_2O_2/TiO_2	3 Antibiotics	UV lamp: $\lambda = 365$ nm; concentration of TiO_2: 1.0 g L^{-1}; ambient pH = 5; reaction time: 30 min	Simulated water	100% Degradation of three compounds; time based rate constants: 0.007 min^{-1} (Amoxicillin); 0.003 min^{-1} (Ampicillin); 0.029 min^{-1} (Cloxacillin)	[75, 76]
Photocatalysis oxidation					
Solar photo-Fenton	9 Pharmaceuticals	Total illuminated area: 3 m^2; solution pH = 2.8; solar ultraviolet irradiation λ <400 nm; irradiation power: 30 W m^{-2}; ion concentration: 5 mg L^{-1}; initial amount of H_2O_2: 50 mg L^{-1};	Effluent from municipal WWTPs	>90% of all compounds: Acetaminophen; Antipyrine; Atrazine; Caffeine; Diclofenac; Isoproturon; Progesterone; Sulfamethoxazole; Triclosan	[77]
TiO_2 photo-catalysis	Ofloxacin and Atenolol	Initial pH: 6–9.6; UVA lamp: 9 W, λ: 350–400 nm; photon flux: 3.37×10^{-6} Einstein s^{-1}; concentration of TiO_2: 250 mg L^{-1}	Pure water, groundwater and treated municipal effluent	>60% (at 5 mg L^{-1})	[78]
Chemical oxidants					
Chlorine dioxide (ClO_2)	9 Pharmaceuticals	Concentration of ClO_2 in aqueous solution: >8 g L^{-1}; solution pH = 7; $T = 20°C$	Drinking water, lake water and groundwater	Only 4 compounds degraded; second-order rate constants: 6.7×10^3 M^{-1} s^{-1} (Sulfamethoxazole); 2.2×10^2 M^{-1} s^{-1} (Roxithromycin); ~2×10^5 M^{-1} s^{-1} (17α-ethinylestradiol); 1.05×10^4 M^{-1} s^{-1} (Antiphlogistic diclofenac)	[79]

(*continued*)

Table 4 (continued)

Tertiary treatment	Compounds	Parameters and conditions	Matrix	Removal (%)	References
Ultrasonic irradiation					
Combined ultrasound/ Fe^{2+}/TiO_2 photoassisted process	EDCs: Bisphenol A	Fe^{2+}: 0.56 and 5.6 mg L^{-1}; TiO_2 :10 and 50 mg L^{-1}; Solar lamp: <300 nm; T: 22±2°C	Milli-Q water	>95%	[80]
Adsorption					
Granular activated carbon (GAC)	29 EDCs and pharmaceuticals	T: 20–25°C; diameter of GAC: 30-ft	Effluent from municipal WWTPs	From >15 (Ibuprofen) to >90 (Pyrene)	[81]
Activated charcoal	Estriol	Surface area of activated charcoal: 99.5 m^2 g^{-1}; sieved size: 0.71–1.4 mm; $T = 30 \pm 1$°C	Distilled water, untreated and treated domestic sewage	>90	[82]

[a] *WW* Wastewater
[b] *STW* Sewage treatment work
[c] *MCPA* 2-Methyl-4-phenoxyacetic acid
[d] *4-AA* 4-Amino-antipiryne
[e] *4-AAA* *N*-acetyl-4-amino-antipiryne
[f] 4-FAA: *N*-formyl-4-amino-antipiryne

of approaches and techniques recently developed will tremendously enhance these investigations and open new possibilities for constructed wetlands.

Membrane Treatment

Membrane technologies such as NF, ultrafiltration (UF), and RO are technologies with high efficiencies in organic and inorganic pollutants removal, including EDCs, pharmaceutical active compounds (PhACs), and pesticides [46, 85]. The following processes by membrane filtration as extra treatments usually operate together with conventional treatment and can overcome the shortcomings of the traditional methods. Because of the irreplaceable advantages such as low energy cost, chemicals requirements only for membrane cleaning, and relative uncritical scale-up under ambient conditions, a number of articles have proposed membrane processes in micropollutants elimination which have been achieved much attraction [86, 87]. Because of their complete or near complete removal of a wide range of organic micropollutants [88], they are increasingly used for water treatment. Many researchers have evaluated the removal mechanisms of NF/RO membranes to trap various pharmaceuticals [64, 89]. The mechanisms can be explained as size/steric exclusion, hydrophobic adsorption and partitioning, and electrostatic repulsion [85], considering the identification of compound physicochemical properties and membrane characteristics in micropollutants transport, adsorption, and removal.

A broad range of micropollutants including PhACs and EDCs was selected as target molecules for a study with NF/RO membrane. For example, Wang et al. [61] focused on the rejection of cyclophosphamide (CP) by NF/RO membrane; more than 90% of CP is removed by RO membrane under all operation conditions, while 20–40% from Milli-Q water and around 60% from membrane bioreactor (MBR) effluent by NF membrane. The individual contributions of the influencing factors including different matrices were identified during his research. The rejection of PPCPs by NF/RO membrane was enhanced in the presence of organic matter when a natural water matrix was used. The removal of frequently used antibiotics from model wastewaters of manufacturing plant by NF/RO membranes was studied [89]. In addition, the optimal membrane type and the operating conditions for the pilot experiments with real wastewater were investigated. Tetracyclines were observed to have a high adsorptive affinity for the NF membrane, while the rejection of sulfanamides was low compared to hormones and tetracyclines [64]. The rejections of these micropollutants were influenced by addition of calcium, organic matter, and salinity. Considering the speciation of molecules, changing of their charge as a function of pH will significantly influence their rejection on membranes [63]. Therefore, increased rejection of micropollutants could be expected due to electrostatic repulsion with membrane surface based on their logKow values. It is reported that polar and charged compounds have a better removal in NF/RO processes due to interactions with membrane surfaces [14, 15]. Radjenović et al. [63] explained that the mechanism of size exclusion brought about very high rejections (i.e., >85%) for uncharged solutes of carbamazepine, hydrochlorothiazide, propyphenazone, and glibenclamide that have molecular weight (MW) greater than the MWCO of NF/RO membranes, whereas in the case of acetaminophen the retention was lowered (i.e., 44.8–73%), probably due to its small molecular size (i.e., MW < MWCO).

The efficacy of natural hormone estrone rejections can be enhanced by different materials of NF/RO membrane [65]. Two conclusions were elucidated that the rejection of trace hormone during NF/RO membrane process was improved by hydrophobic acid macromolecules, and the removal of calcium ions via pretreatment and application of membrane with more negative charge at its interface can greatly intensify this "enhancement effect". The combination of UF and activated carbon adsorption was proved to be an attractive alternative for organic xenobiotics removal [90], including a broad range of representative EDCs and PPCPs during drinking and wastewater treatment processes at bench, pilot, and full-scale [81].

Most studies primarily focus on the rejection of micropollutants by NF/RO membrane in laboratory scale, with reporting of complete or near complete removal. However, membrane fouling remains a persistent technical hindrance in their full-scale application. Different types of fouling such as inorganic, particulate, and colloidal fouling, organic, and biofouling can occur on membrane surface [91]. Although in some cases, organic fouling could both improve and lessen the retention of PhACs by NF membranes, and frequent membrane fouling by inorganic and organic/biological contaminants in the feed water still represents a major problem from both technological and economical perspective [92]. It is observed as accumulation and adsorption of contaminants on the surface or in the pores of the membrane, resulting in permeate flux reduction [93]. Wei et al. [87] reported that the deposition of sulfate and carbonate of calcium was the main cause of membrane fouling at the initial stage, and then complex organic foulants containing carboxyl acid, amide, and alkyl halide functional groups also deposited onto membrane surface and gradually formed a densely packed fouling layer. According to this, actions must be taken in effective prevention of membrane fouling in NF/RO processes. Using different types of detergents to clean the foulant elements on surface of membrane is a popular solution [94]. The pretreatment of microfiltration (MF) [95] or ozonation [96] is proved to be effective in reducing fouling of membranes. Moreover, surface modification of existing, commercially available membranes by antifouling coatings has attracted considerable attention, such as dendrimer nanotechnology [92]. It may provide a novel approach to the solution of this very important problem in membrane filtration.

Beside the membrane fouling, the cost of disposal or treatment of the resultant RO concentrate represents another main disadvantage. These membrane concentrates include an increased amount of salts, organics, and biological constituents, also including these micropollutants. Pérez [97] suggested the electro-oxidation technology to remove ten emerging contaminants in RO concentrates; more than 92% of removal percentages were obtained in all the cases after 2 h oxidation.

Advanced Oxidation Processes

Among all the tertiary treatment processes, the AOPs appear more practical in comparison with other technologies over the past 30 years. The traditional technologies have effectiveness on removal of PhACs through filtration or absorption and only transfer the pollutants from one phase to another without destroying them [75, 76]. However, AOPs can work alone or combine with other destructive technologies to completely degrade chemicals, based on the intermediacy of hydroxyl and other radicals to oxidize recalcitrant, toxic, and nonbiodegradable compounds to various by-products and eventually to inert end products [51]. The metabolites which are formed during AOPs can also be harmful compounds; these intermediates should also be removed, named mineralization as the main aim of these processes.

Therefore, literature already reports multiple examples of the use of these AOPs on the removal of various micropollutants. Among these, ozonation is proposed as a suitable tool for high transformation of the organic pollutants from oxidation intermediates into inorganic carbon. It involves the use of ozone combined with catalysts or promoters of ozone decomposition in free radicals [98, 99]. Because of its high oxidation potential, ozone treatment is widely used in a wide spectrum of removal of micropollutants including pharmaceuticals, EDCs, and pesticides during bench-, pilot-, and full-scale experiments [100, 101]. In addition to ozonation, several other advanced oxidation technologies have been extensively used for the degradation of micropollutants. UV irradiation and chlorine disinfection have been demonstrated as capable of attracting PhACs species [23, 36, 74]. It is widely used in the secondary effluent of some WWTPs, before it is released into the environment. Oxidation by the Fenton's reagent is found quite effective in treatment of aqueous solution containing emerging contaminants [42, 43, 102]. Although the reactions of Fenton's reagent are potentially useful oxidation processes for organic compounds elimination, the related reports are few in the literature. Most of the oxidation processes considering Fenton's reagent are combined with photocatalysis, such as solar photo-Fenton system [77]. These heterogeneous photocatalysis shows advantages in PPCPs abatement from STP effluents, like TiO_2 photocatalysis [78, 103], photocatalytic ozonation [98], and photolysis in the presence of Ferrate [104]. Other technologies are less conventional but evolving processes include electrolysis [105] and ultrasonic irradiation [106].

Although AOPs have been recognized as predominant technique for oxidizing and mineralizing almost any organic contaminant, the high demand of electrical energy for devices such as ozonators and UV lamps is one of the drawbacks that cannot be ignored in commercial application. Considering the economical disadvantages, future applications of these processes could be improved through the use of ultrasound and solar energy [107, 108].

Ozonation

Ozone is one of the most popular and strong oxidant which is widely used for the reduction of various organic matters contained in the secondary effluent.

It decomposes in water to form hydroxyl radicals which are stronger oxidizing agents than ozone itself and reacts with organic contaminants through both direct and indirect reaction by ozone or free radicals, respectively. Multiple degradation pathways are proposed to happen during ozonation process, such as breaking of large molecules into smaller ones and partial and complete mineralization of organic matter. In some cases, these ozonation transformations of micropollutants are easier to occur at certain conditions by reaction of free radicals. Thus, the rate of OH· formation is extremely important in removal of micropollutants. Different conditions of water matrices, especially their pH, alkalinity, type, and content of natural organic matter, all have influence on the formation of free radicals [109]. Therefore, the important parameters such as ozone dosage, matrix acidity, temperature, and organic matter in the matrix should be taken into account for explaining the ozone efficiency.

Depending on the type of the matrices and the operating conditions, ozone oxidation is usually favored at increased pH values due to the increased production of hydroxyl radicals. The fastest degradation at pH 10 is obtained by ozonation of 45.3 μM ciprofloxacin in hospital WWTPs effluent, which is explained by the direct ozonation at unprotonated amines of the piperazinyl substituent [67]. In case of ozonation of clarithromycin, the ozonide radical anion is stable at high pH only, but near pH 7 it is rapidly protonated by water and decomposes into O_2 and OH [68]. Witte et al. [110] report that the removal of levofloxacin is about two times faster at pH 10 compared to pH 3 and 7 explained by direct ozonation, and the degradation pathways being strongly affected by changes in pH. However, the effects of pH and oxidant doses on the efficiencies of ozone oxidation processes are studied in terms of oxytetracycline (OTC) removal, and the OTC elimination is not affected by the pH adjustment of the manure slurry [111]. Referred to the ozone dosage, pharmaceuticals (and more generally the xenobiotics present) could be converted into compounds even more toxic than the parent species with low ozone dosage [66]. In combination with hydrogen peroxide, ozonation seems more attractive for wastewater reuse, as higher concentration of hydroxyl radicals' formation during treatment processes. Rosal et al. [112] reported the removal of dissolved organic matter enhanced by adding periodic pulses of hydrogen peroxide, leading to almost complete mineralization in less than 1 h. Dodd et al. [113] determined the second-order rate constants of 14 pharmaceuticals with ozone and hydroxyl radicals. The addition of H_2O_2 to ozonation abets contaminant removal, and at mole ratio of $H_2O_2/O_3 = 5$, it attains the highest degradation speed for sulfonamide and macrolide antibiotics [38]. It is also reported that the degradation of erythromycin having a fully saturated structure is slower and more effective at higher pH or with added H_2O_2. But only a small dose of H_2O_2 is desirable when widely disparate compounds are treated by ozonation. For example, H_2O_2 concentration (2–100 μM) had only limited effect on the degradation rate of levofloxacin during ozonation [110]. H_2O_2 accelerated the rate of O_3 decomposition into ·OH, but did not enhance the overall OH exposure during ozonation. The addition of H_2O_2 to ozonation in a nonoptimized manner cannot result in higher removal of pharmaceuticals from wastewater. Snyder et al. [114] removed over 90% of some target compounds but less than 50%

of others, and removal was improved only marginally when H_2O_2 was added to promote treatment via AOPs.

Besides O_3/H_2O_2, other ozone-based AOPs technologies are also applied in various effluents. Ozone involving oxidation processes: ozone alone (O_3) and combined with UVA radiation (O_3/UVA, ozone photolysis) and titania (O_3/UVA/TiO_2) are compared to remove the PPCPs [100]. The O_3/UVA/TiO_2 oxidation is especially recommended to achieve a high mineralization degree of water containing sulfamethoxazole (SMT) type compounds. Considering other compounds, Ternes et al. [52] concludes that O_3/UV slightly increased the oxidation efficiency for some ICMs in comparison to ozonation. Naddeo [108] introduces the ultrasound in enhancing the O_3 decomposition of diclofenac and led to higher mineralization (about 40%) for 40 min treatment and to a significantly higher mineralization level for shorter treatment duration. Ozonation and activated carbon treatment might be beneficial for ecosystem health as these techniques provide effective barriers to organic contaminants [115].

However, ozone is an expensive oxidant, and ozonation carries the inherent danger to produce toxic oxidation by-products. Mineralization of pharmaceuticals, for example, ranges from insignificant up to 50% depending on the compound [51]. Because organic compounds are often not mineralized entirely but transformed to unknown intermediates, it should be investigated whether toxicity increases after ozonation and if a subsequent treatment is sufficient to remove these toxic products.

UV Irradiation

In previous studies, ultraviolet (UV) radiation has been widely used in tertiary disinfection treatment in WWTPs and swine wastewater treatment [116]. The UV disinfection is generally applied using low-pressure mercury lamps emitting monochromatic light at 254 nm. It can decompose organic compounds including pharmaceuticals by direct photolysis, or by indirect photolysis through an AOP, especially the hydroxyl radicals can also be generated in UV/H_2O_2 process and further promote organic compound oxidation. The efficacy of oxidation and mineralization depends on different organic pollutants. Yuan et al. [73] observed that the rates of direct photolysis of ibuprofen and diphenhydramine were low, while phenazone and phenytoin occur at a higher rate at same condition. Some contaminants are degraded by direct UV disinfection such as ketoprofen, diclofenac, ceftiofur, sulfamethoxazole, sulfamonomethoxine and antipyrine [117]. According to the reports, UV disinfection does not produce any regulated disinfection by-products (DBPs) in contrast to chlorine as disinfectant [23]. Regarding the toxicity profile, the trend of the inhibitory concentration (IC_{50}) values indicates that the MET phototransformation favors the formation of intermediates with higher toxicity than the MET raw solution [74]. It is expected that applying UV/H_2O_2 process might be able to further degrade micropollutants in WWTP effluent. For instance, the degradation of atrazine by UV/H_2O_2 at various UV intensities at a wavelength of 253.7 nm was investigated for a wide range of H_2O_2 dosages [118], and the results demonstrate that UV/H_2O_2 greatly improves the removal of atrazine compared to sole-UV and dark-H_2O_2. Li et al. [119] indicate that clofibric acid (CA) degradation takes place mostly by indirect oxidation through the formation of •OH radicals in UV254/H_2O_2 process, and higher temperature would favor CA degradation whereas humic acid (HA) has negative effect on CA degradation, and this effect is much more apparent under low temperature condition. UV/H_2O_2/TiO_2 photocatalysis is also suggested to be effective for degradation of selected pharmaceuticals in aqueous solution. Elmolla and Chaudhuri [75, 76] achieve complete degradation of amoxicillin, ampicillin, and cloxacillin by the addition of H_2O_2 at ambient pH ~5 and TiO_2 1.0 g L^{-1} in 30 min.

There are many other conditions that should be considered during UV irradiation, such as water quality (i.e., alkalinity, nitrite, and specifically effluent organic matter (EfOM)) and water matrices. Rosario-Ortiz et al. [41] evaluated the role of water quality on hydroxyl radical exposure and six pharmaceuticals removal between the three wastewaters. It indicates that the overall removals of these pharmaceuticals are between 0% and >99%, and the intrinsic reactivity of the EfOM is an important parameter. In addition, the pH-induced photolytic treatment has a potential in improving treatment of antibiotics in mixtures. In cases of sulfamethoxazole (SMX), oxytetracycline (OTC), and ciprofloxacin (CIP), an increase in water pH from 5 to 7 leads to a decrease in degradation rate of SMX and an increase in degradation rate of OTC and CIP [120]. UV radiation could be a promising option for removal of micropollutants in secondary effluents, but due to high UV doses required it will not be economically competitive with other types of treatment in the near future [121].

Photocatalysis Oxidation

More and more technologies classified as AOPs make use of a combination of either oxidants or irradiation. To reduce the cost of electrical energy for devices such as ozonators and UV lamps, the use of catalysis and solar energy is suggested for commercial applications. According to the report from Paul et al. [122], UV photolytic and TiO_2 photocatalytic [using both UVA and visible light (Vis) irradiation] treatment processes are compared in the removal of ciprofloxacin (CIP) in deionized water. Rates of CIP degradation under comparable solution conditions (100 mM ciprofloxacin, 0 or 0.5 g L^{-1} TiO_2, pH 6, 25°C) follow the trend UVA-TiO_2 > Vis-TiO_2 > UVA. But this is preceded in deionized water, and it should be kept in mind that natural and wastewater matrixes often contain constituents that attenuate solar and UV light or scavenge hydroxyl radicals. Klamerth et al. [123] investigated the degradation of 15 emerging contaminants (ECs) at low concentration in simulated and real effluent of municipal WWTP with photo-Fenton at unchanged pH and Fe = 5 mg L^{-1} in a pilot-scale solar CPC reactor. The degradation is found to depend on the presence of CO_3^{2-} and HCO^{3-} and on the type of water. Complete degradation is also found in high concentration (more than 100 mg L^{-1}) of amoxicillin, ampicillin, and cloxacillin solution in 2 min with photo-Fenton treatment (UV 365 nm) [42, 43]. The release and mineralization of organic carbon and nitrogen in the antibiotic molecule are proposed. In addition, the photo-Fenton oxidation using UVA lamp has effect on elimination and mineralization of ofloxacin and atenolol, considering experimental conditions such as catalyst type and loading, initial substrate concentration, and pH [78]. The toxicity is completely removed by photocatalytic treatment, and this is more pronounced for atenolol. Besides Fenton's reagent, TiO_2 is considered to play an important role in the degradation of sulfa pharmaceuticals [124]; three sulfa pharmaceuticals are completely mineralized into CO_2, H_2O, and inorganic ions within 240 min, and removal efficiencies of 85.2%, 92.5%, and 85.0% after 60 min illumination are obtained. Two tentative degradation pathways for the photocatalytic degradation are proposed; reactive oxygen species (ROSs) indicates that both photohole (h+) and, especially, hydroxyl radical (•OH) are responsible for the major degradation of sulfa pharmaceuticals. Sirés et al. [125] tested clofibric acid (CA) degradation by electro-Fenton and photoelectron-Fenton processes and found that about 80% of CA mineralization was achieved with the electro-Fenton process and more than 96% of CA removal by photoelectron-Fenton process.

Other Chemical Oxidants

Chemical oxidants are commonly used in water treatment processes; chlorine, chlorine dioxide, hypochlorite, and ferrous ions are attractive reagents for oxidation of micropollutants. The ferrous ions have been proved to strongly promote the oxidation of maleic acid by hydrogen peroxide for at least 100 years [102]. Fenton's reagent consisting of H_2O_2 and Fe(II) is one of the most effective advanced oxidation agents used for degradation of recalcitrant organic compounds, as well as like Fenton's reagents [Fe(III)/H_2O_2]. Because of its high oxidation potential (2.8 V) of hydroxyl radicals, it has been commonly used for degradation of nonbiodegradable chemicals. According to the results of Li et al. [102], Fenton's reagent composed of $FeSO_4$ and 5% H_2O_2 is found to be highly efficient for the selective oxidation of 2,3,6-trimethylphenol to the corresponding benzoquinone under mild conditions. Direct oxidation by the Fenton's reagent is proved to be effective in complete removal of amoxicillin, ampicillin, and cloxacillin in 2 min [42, 43]. In the following study, complete amoxicillin degradation is also obtained within 2.5 min; the optimum H_2O_2/Fe(II)/amoxicillin ratio resulting in complete amoxicillin degradation and 37% mineralization is 255/25/105 mg L^{-1} [126].

Because of its low cost, chlorine is popularly applied in drinking water disinfection at the beginning or for post-treatment. As the last step in WWTPs, it plays an important role in limiting the pollutants. Chlorine can transform numerous inorganic and organic micropollutants found in water [127, 128]. During chlorination processes, HOCl is the major reactive chlorine species. For the compounds with phenol structure, the main chlorination is expected on the phenolic ring. Mash et al. [129] investigates the hypochlorite oxidation of a select number of androgenic compounds, and the results show that compounds that possess a ketonic functional group conjugated with a double bond inhibit oxidation by hypochlorite in the absence of biological or indirect oxidative pathways. For certain compounds, the chlorine reactivity is low and only small modifications in the parent compound's structure are expected under typical water treatment conditions. Compared to chlorine, ClO_2 is a stable free radical with the major reduction product chlorite, and more effective inactivation of protozoa. For example, of the nine pharmaceuticals the following four compounds showed an appreciable reactivity with ClO_2, such as the sulfamethoxazole, roxithromycin, 17a-ethinylestradiol, and diclofenac [79]; however, many other compounds in the study were ClO_2 refractive. Obviously, ClO_2 reacted more slowly and with fewer compounds compared with ozone, which exhibits higher rate constants and reacts with a large number of pharmaceuticals. But chlorination is expected to oxidize a relatively large number of pharmaceuticals, despite its lower oxidation potential compared to ozone and hypochlorous acid.

Considering the efficacy of different oxidants, Lee et al. [130] studies the selective oxidants including chlorine, chlorine dioxide, ferrate VI, ozone, and nonselective hydroxyl radicals with respect to their efficiency for transforming micropollutants during the treatment of the wastewater effluents. For a given oxidant dose, the selective oxidants were more efficient than hydroxyl radicals for transforming electron-rich organic moieties (ERMs)-containing micropollutants. However, the selective oxidants react only with some ERMs, such as phenols, anilines, olefins, and deprotonated amines. In contrast, hydroxyl radicals show a very high reactivity ($k \geq 10^8$ M^{-1} s^{-1}) with almost all organic moieties, even including C–H bonds. Besides EfOM, ammonia, nitrite, and bromide were found to affect the micropollutants transformation efficiency during chlorine or ozone treatment.

Ultrasonic Irradiation

Ultrasonic irradiation is less conventional but evolving processes among the various AOPs. The application of ultrasound for the degradation of pollutants in the wastewater attracts considerable interest [80, 108]. Sonolytic degradation of pollutants is based on continuous formation and collapse of cavitation bubbles on a microsecond time scale. Hot nucleus is formed and characterized with extremely high temperatures at the same time. Sonication has been attempted for elimination of micropollutants found in environmental water only recently, such as pharmaceuticals of ibuprofen [131], diclofenac [108], triclosan [132], EDCs of bisphenol A [133], and pesticide of parathion [134]. The mixture solution of diclofenac, amoxicillin, and carbamazepine spiked in urban wastewater effluent is degraded by sonolysis [106, 135]. Several operation conditions (power density, initial substrate concentrations, initial solution pH, and air sparging) are evaluated for promoting the treatment processes. Sonication is only merely been attempted for investigating the degradation pathways and explain the initial pathways by the molecular orbital theory. Naddeo et al. [106] points the main pathways of parathion degradation by ultrasonic irradiation. First, the N_2 in air takes part in the parathion reaction through the formation of $\bullet NO_2$ under ultrasonic irradiation. Then parathion is decomposed into paraoxon and 4-nitrophenol in the first step via two different pathways. It would be more complex when taken into account the influence of environmental water matrices.

Adsorption

One of the most efficient and promising fundamental approach for multicompounds elimination is adsorption. It is recognized as a surface phenomenon by attracting of multicomponents fluid (gas or liquid) mixture to the surface of a solid adsorbent and forming attachments via physical or chemical bonds. Recently, many researches demonstrate that adsorption technology can be highly effective for the removal of emerging contaminants [82, 136]. Among the diversity of absorbents, a notable trend in the development of activated carbon (AC) is widely observed [50]. Based on the advantage of large porous surface area, controllable pore structure, thermo-stability, and low acid/base reactivity, AC mainly hinges on its superior ability for removing a broad type of organic and inorganic pollutants dissolved in aqueous media. Most of the AC is commonly applied as powdered feed or in a granular form, named granular activated carbon (GAC), which is highly effective at removing hydrophilicity compounds [81]. Moreover, Kumar et al. [82] reported the removal of Estriol (E3) by adsorption process of activated charcoal as adsorbent, and agitated nonflow batch sorption studies show good E3 removal efficiency. Different matrices of distilled water, untreated domestic sewage, and treated domestic sewage are studied in fixed bed column with E3 spiked, to assess the potential of sorption process as tertiary unit operation in the WWTPs.

As compared to activated carbon or charcoal, the polyacrylic ester adsorbents have been successfully applied for removal and recovery of highly water-soluble compounds from water and wastewater, due to their polar and hydrophilic characteristics [137]. Besides its satisfied adsorption, the exhausted polymeric adsorbents can be amenable to an efficient regeneration under mild conditions like acid or alkaline rinsing. According to their following study, Pan et al. [138] elucidate that hydrophobic interaction and electrostatic interaction play a synergetic role in effectively scavenging sulfonated pollutants by a polyacrylic ester adsorbent NDA-801. It is well recognized that the hydrophobic interaction plays a favorable role in adsorption. However, Navalon et al. [11] found that dealuminated zeolites are significantly more efficient for removal of hydrophobic organic matter than the polymeric resins.

A novel technology of adsorption is referred to nanotechnology, which has introduced different types of nanomaterials to water industry that can have promising outcomes. Nanosorbents such as carbon nanotubes (CNTs) possess fibrous shape with high aspect ratio, large accessible external surface area, and well-developed mesopores. They contribute to the superior removal of various contaminants [139]. According to the previous studies [140], CNT technology can possibly avoid difficulties of treating biological contaminants in conventional water treatment plants, and thereby remove the burden of maintaining the biostability of treated water in the distribution systems.

Similar to adsorption treatment processes, another kind of adsorption that goes through subsurface soil–aquifer passage is capable to attenuate a subset of polar and persistent emerging pollutants [136]. As wastewater indicators for assessing the potential of pollutants to leach into groundwater, two antiepileptic drugs (carbamazepine, primidone), one sulfonamide (sulfamethoxazole), and one corrosion inhibitor (benzotriazole) are studied with three soils differing significantly in their organic matter content. Not only conditions possible adsorption mechanisms rely on hydrophobic interactions, ionic attraction, and hydrogen bonding are functioned as the adsorption mechanism.

Although the reported adsorption technologies have been successfully applied on industrial scale, there are still various constrictions, such as the economically viable technology and sustainable natural resources management (cost-prohibitive adsorbent and difficulties associated with regeneration). A large number of adequacies, natural, renewable and low cost materials are expected to be developed as alternative precursors in near future.

4 Case Study: Reused Water in Catalonia Spain

4.1 Scenario Description

A recent work investigated the impact of discharges of tertiary treated sewage on the load of polar emerging pollutants in a Mediterranean river during a water reuse period [141]. Data gathered in these experiences were carried out in the low part of the Llobregat River (NE Spain), in the surroundings of the town of Barcelona during the fall of 2008, as a consequence of the severe drought that took place along the years 2007–2008 in the area are presented as illustrative example. The Llobregat River (NE Spain) is 156-km long and covers a catchment area of about 4,957 km^2 (Fig. 6). From the hydrological point of view, the Llobregat is a typical Mediterranean river; its flow being characterized by a high variability, which is closely controlled by seasonal rainfall. The mean annual precipitation is 3,330 hm^3 and it has an annual average discharge of 693 hm^3. The average monthly flow registered since year 2000 shows peaks of ca. 100 $m^3\ s^{-1}$, together with minimum values of ca. 1 $m^3\ s^{-1}$ percent (relative standard deviation of 124%). Its watershed is heavily populated with more than three million inhabitants living therein. Together with its two main tributaries, River Cardener and River Anoia, the Llobregat is subjected to a heavy anthropogenic pressure, receiving extensive urban and industrial waste water discharges (137 hm^3 per year; 92% coming from the WWTPs), which constitutes a significant part of its flow [69–71].

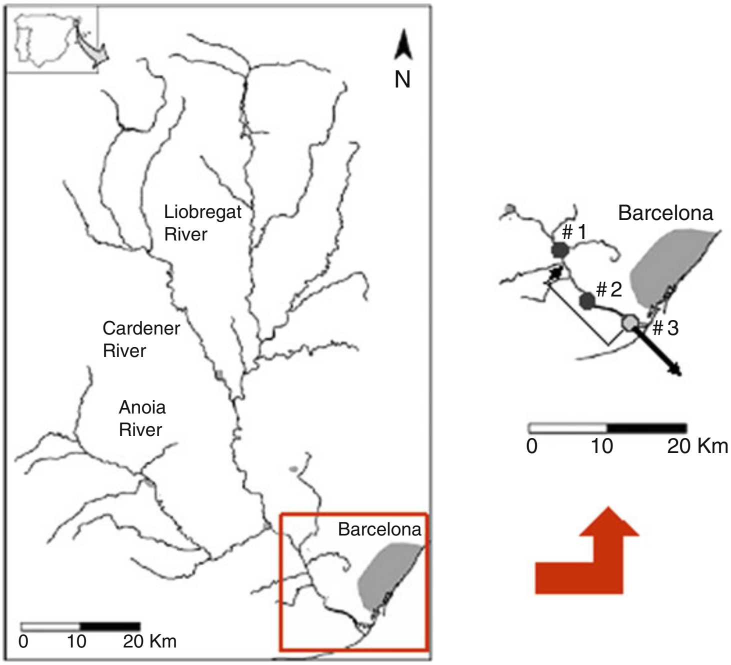


Fig. 6 Sampling points location in the lower stretch of the Llobregat River. Point 1 Llobregat River at Molins de Rei; point 2 Llobregat River at Sant Joan Despí; point 3 WWTP El Prat de Llobregat

The section concerned with the present work corresponds to the last part of the river, between the populations of Molins de Rei (point 1) and Sant Joan Despí (point 2), the later being particularly relevant because the intake of an important drinking water treatment plant supplying water to Barcelona is located there. Treated water from the WWTP tertiary treatment of El Prat de Llobregat (point 3) is pumped upstream ca. 15.6 km and discharged into the river, at 0.2 km downstream of reference point 1 (Fig. 6). For the purposes of the present work, it is worth noting that the total treated wastewater discharged in the Llobregat basin upstream to point 1 is ca. 96 hm^3 per year, corresponding to 1,346,790 equivalent inhabitants.

4.2 Micropollutant Occurrence

Five groups of emerging organic contaminants, namely pharmaceutically active substances (PhACs), illicit drugs, polar pesticides, estrogens, and alkylphenols and related ethoxylates, in WWTP tertiary treatment effluents and the receiving surface waters were analyzed. Presence of emerging contaminants in environmental waters is directly related to their removal in WWTP and the flow rate of the receiving river waters. Moreover, Mediterranean rivers are characterized by important fluctuations in the flow rates and heavy pollution pressures resulting from extensive urban, industrial, and agricultural activities. This translates into contamination levels in these rivers often higher than in other larger European basins.

Concentration values obtained for most of the pollutants in river water and tertiary treated sewage are in the low to mid-nanograms per liter range (Fig. 10), similar or slightly below to those reported previously in the Llobregat River or in other Spanish Mediterranean rivers. With the exception of estrogens only present in tertiary treated sewage waters at very low concentrations, all the remaining families were detected both in the river and in the tertiary effluents at comparable levels. In general, detected concentrations of the target analytes are similar or slightly below to those reported previously in the Llobregat River or in other Spanish Mediterranean rivers. The detection of a broad spectrum of organic pollutants corroborates the heavy impact of contaminant sources in the river such as households, industry, and agriculture.

4.3 Removal of Micropollutants After Chlorination

Depending on the final use of the reclaimed water, a disinfection step is introduced as last part of the process to fulfill microbiological quality requirements. In the case under study, chlorination with sodium hypochlorite was the disinfection agent of choice, which is commonly used in both reclaimed and drinking water treatment.

Although the primary objective of chlorination is not the removal of micropollutants, since hypochlorite is a fairly strong oxidant, it may also contribute to the depletion of certain compounds. With the aim to check the effect of the chlorination step on the elimination of the target compounds (PhACs, illicit drugs, polar pesticides, estrogens and alkylphenols, and related ethoxylates), water samples were collected before and after chlorination (chlorination influent – CHLInf and chlorination effluent – CHLEf, respectively). Note that in this section the influent is the tertiary effluent of the WWTP, before the last chlorination step. Figure 7 shows the influent concentration (CHLInf) of all target families as well as the relative removal after the chlorination.

4.3.1 Pharmaceuticals

Concerning to the input levels to the chlorination process, the most representative families were, as expected, pharmaceuticals such as analgesics, anti-inflammatories, lipid regulators, and cholesterol lowering statin drugs, antihypertensives, and antibiotics as fluoroquinolone and macrolides. Only the antihypertensives accounted for almost 30% of the total CHLInf levels of target families. Regarding this pharmaceutical family, the main contributor was hydrochlorothiazide (HCTZ) reaching levels higher than 1,500 ng L^{-1}. This pharmaceutical belongs to the thiazide class of diuretics and is often used in the treatment of hypertension. Other pharmaceutical families presented levels below 700 ng L^{-1}.

As regards as removal, the highest performance occurred for tetracycline antibiotics and diuretics with more than 90% of elimination. Conversely, the less

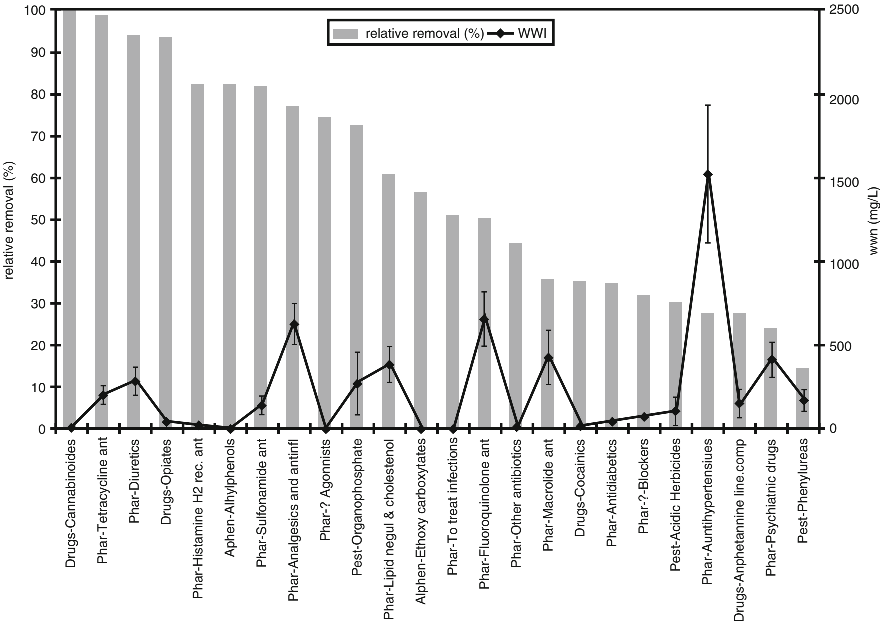


Fig. 7 Relative removal (% of secondary effluent of the WWTP) after the tertiary treatment and wastewater influent concentration (WWI) of target families

affected families by chlorination were psychiatric drugs and antihypertensives, with less than 30% of elimination.

4.3.2 Pesticides

In what pesticides are concerned, the most representative group were organophosphates and particularly diazinon, a nonsystemic organophosphate insecticide formerly used to control cockroaches, silverfish, ants, and fleas in residential, nonfood buildings. Diazinon has a relatively high solubility and it is thus easily found in water. Other important group is constituted by triazine compounds. Some families like triazines or anilides show high levels both in influent and effluent (in some cases, such as propanil, the levels at the output are even higher than the input).

4.3.3 Estrogens

In the case of estrogens, compounds that can cause negative effects to the endocrine functions of wildlife, posing an environmental risk [142] estradiol was not detected before the chlorination treatment, but after that 64 ng L^{-1} was found in one sample. Some explanation is that estrogens are mostly present as glucuronide, sulfate, or sulfo-glucuronide conjugates, and due to the physical chemical changes in the chlorination, these conjugates may suffer deconjugation [143]. However, this result, found in a single sample, should be further confirmed.

4.3.4 Illicit Drugs

Opiates and cannabinoids presented a good elimination (>90%) in the chlorination process; in contrast, cocainics and amphetamine-like compounds showed eliminations lower than 40%. This last family not only presented the less removal rate, but was the most contributing family, with input levels between 57 and 89 ng L^{-1} (MDMA and ephedrine, respectively). MDMA, best known for ecstasy, is an entactogenic drug of the phenethylamine and amphetamine families. Ephedrine is a sympathomimetic amine commonly used as a stimulant, appetite suppressant, concentration aid, decongestant, and to treat hypotension associated with anesthesia.

4.3.5 Alkylphenol Ethoxylates

Alkylphenols presented, in general, good response to chlorination and very low WWI levels. Nonylphenol and nonylphenol ethoxylates, which are toxic xenobiotic compounds, classified as endocrine disrupters capable of interfering with the hormonal system of numerous organisms [144], presented concentrations lower than 1 ng L^{-1} and eliminations higher than 50%.

In a global perspective, chlorination has satisfactorily eliminated target compounds (50% of target families presented relative removal higher than 50%). On the other side, chlorination as a disinfection step in the water treatment must be seen with caution, since chlorine can react with organic compounds found in the water to produce chlorinated compounds, known as DBPs. The most common DBPs are trihalomethanes (THMs) and haloacetic acids (HAAs). Due to the carcinogenic potential of these compounds, a lot of WWTPs and drinking water plants are changing the chlorination treatment with hypochlorite by alternative processes with less undesirable side-effects.

4.4 Load Contributions

A further objective of the present case study was to discriminate the relative contribution to the total load (expressed as mass-flow in mass/time units) of the various emerging contaminants found downstream in the river, thus differentiating the load which is already present upstream in the river as "background," from that coming from the discharged effluent. Loads for points 1 and 3 were calculated as the respective product of concentrations per flows [i.e., *Load* (*point j, compound i*) $= Q_j \cdot c_{ij}$]. Both flows and concentrations were taken as the average of the three measurements available.

Assuming a conservative behavior for the contaminants, the load at point 2 (river downstream) corresponds approximately to the load coming from the river upstream (point 1), plus the load discharged (point 3). This can be expressed in the following mass-flow balance equation (1) set for every compound *i*:

$$\text{Load river downstream } (\#2) = \text{Load river upstream } (\#1) + \text{Load eff}l.\text{ discharged } (\#3)$$

$$Q_2 \cdot c_{2i} = Q_1 \cdot c_{1i} + Q_3 \cdot c_{3i} \quad (1)$$

This assumption is reasonable since sampling point 2 and the discharge point were at very close distance with each other (ca. 0.2 km), and other influences in such a short stretch can be considered negligible. Hence, loads were calculated according to the outlined procedure for the five groups of pollutants studied and their relative load contributions could be directly compared (Fig. 8a–f).

It is evident from the figures that the relative contributions were different for each group and for the different compounds within each group (Fig. 8f). Estrogens were the only group which was exclusively detectable in the tertiary effluents, though at very low concentrations (Fig. 8d). In contrast, the presence of alkylphenols derivatives (Fig. 8e) was clearly linked to the upstream river (ca. 80%). Pesticides, if globally considered, showed the opposite situation. However, for the later group compound contributions appeared to be very heterogeneous (Fig. 8b). Thus, for instance, whereas chlortoluron, isoproturon and propanil were clearly associated with the upstream river, 2,4D, mecoprop, and to a lesser extent diuron and terbutylazine were related to the effluent. Other compounds such as atrazine, simazine, or diazinon show a mixed origin.

The other two families showed a mixed behavior, requiring an examination compound by compound. Thus, for instance, in the case of illicit drugs, while amphetamines such as MA and MDMA and the opiate 6ACM appeared to be strongly associated with the tertiary effluent discharge, cocainics were mostly present in waters coming from the upstream stretch of the river (Fig. 8c). Pharmaceuticals constituted the most complex case, as could be expected because of the high heterogeneity of chemical structures and the number of compounds analyzed. Even so, the clear association of analgesics and anti-inflammatories (ibuprofen, naproxen, diclofenac, indomethacin, salicilic acid, phenazone, propyphenazone with the only exception of mefenamic acid) with upstream river water was noticeable. Some histamine H_2 receptors such as famotidine, cimetidine, and ranitidine, the lipid regulators, gemfibrozil, fenofibrate and atorvastatin, the antibiotics trimethoprim and tetracycline, and the diuretic furosemide showed a predominance of the same upstream origin. Conversely, the β-blocker metoprolol, the quinolone antibiotic ofloxacin and norfloxacin, antibiotic macrolides such as azithromycin, erythromycin, or tylosin A, barbiturates, and salbutamol were mostly associated with the WWTP effluent. However, for the great majority of pharmaceutical compounds studied, a mixed contribution (from river upstream and from the effluent discharged) was observed.

Furthermore, loads (mass-flows) provide a straightforward way to compare in bulk the weight of the different pollutant families studied in quantitative terms. The

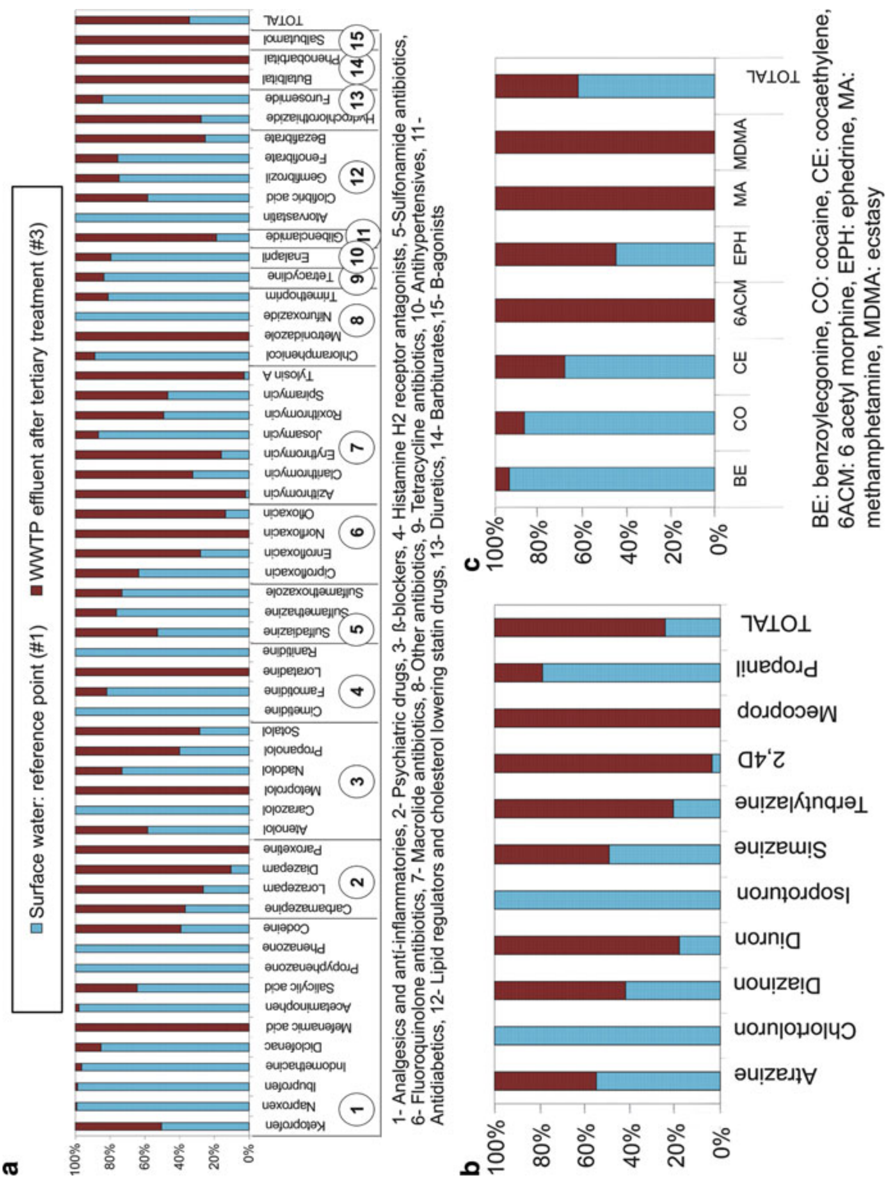


Fig. 8 (continued)

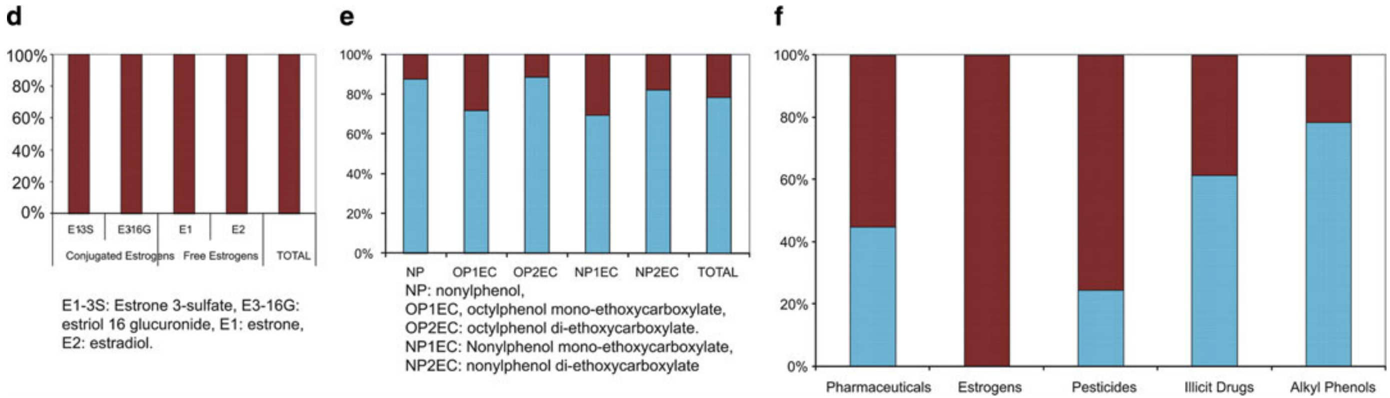


Fig. 8 Relative contribution (%) to pollution loads found in point 1 of (**a**) pharmaceuticals, (**b**) pesticides, (**c**) illicit drugs and metabolites, (**d**) estrogens, (**e**) alkylphenols and ethoxylated derivatives, and (**f**) each investigated group

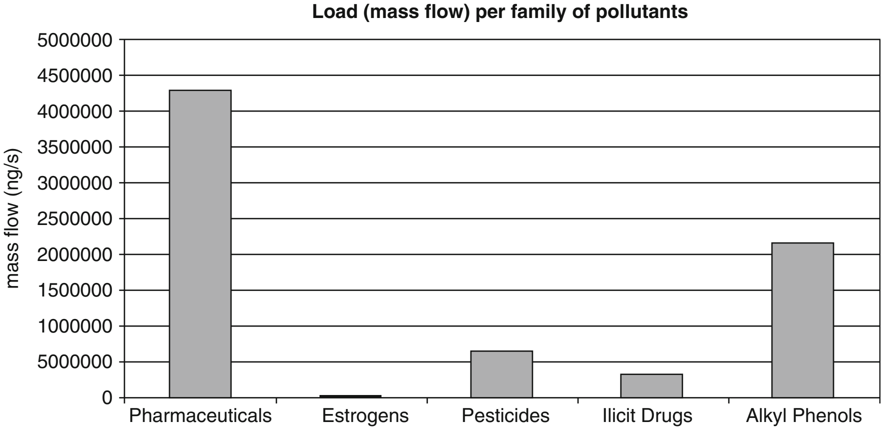


Fig. 9 Calculated and experimental mass-flow balances for each family of micropollutants investigated in point 2

results corresponding to point 2 (river downstream) are summarized in Fig. 9. From that, the following rank order was established:

$$\text{Pharmaceuticals} > \text{Alkylphenols} > \text{Pesticides} > \text{Illicit Drugs} >> \text{Estrogens}$$

4.5 *Mass-Flow Balances*

Still continuing under the assumption of conservative behavior for the contaminants, since both flow and concentrations at point 2 (Q_2 and c_{2i}) are already available from direct measurements, we could compare the predicted value of $c_{2i}(calc)$, which was straightforward calculated from the foregoing mass balance equation to the found $c_{2i}(exp)$. The suitability of the assumptions was thus experimentally checked.

Results obtained are represented for each one of the families studied in Fig. 10a–e. Leaving aside the case of estrogens that were found at detectable levels only in effluents and at very low concentrations, the rest of the groups seemed to acceptably fit the model. Although both positive and negative deviations between calculated and measured values were observed, predicted values slightly higher than measured seemed to predominate. In some cases, such difference could be neglected since it falls within the range of the statistical uncertainty embodied in the results. However, the overestimation could be attributed to several reasons, all of them based on the noncompliance of the balance equation (1). Among others, two possibilities are (1) non-fulfillment of the implicit assumption of conservative behavior, due to the disappearance of the compound by some kind of depletion mechanism occurring in

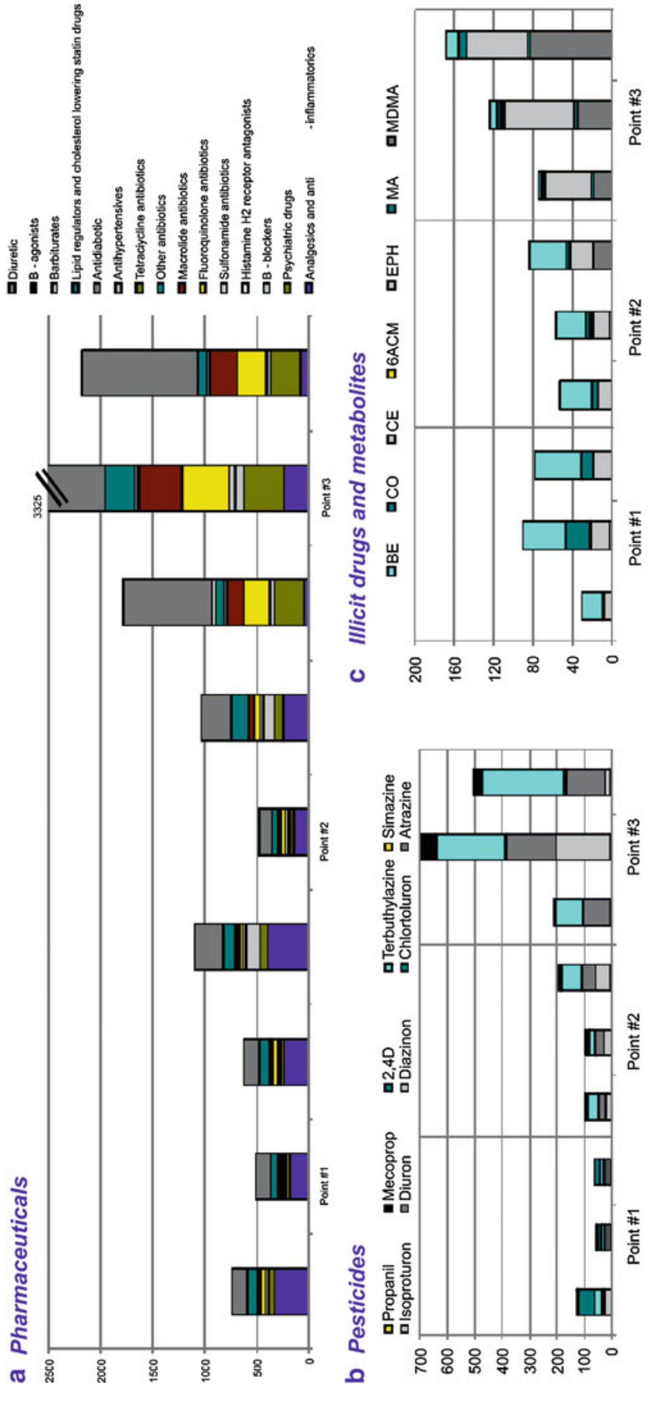


Fig. 10 (continued)

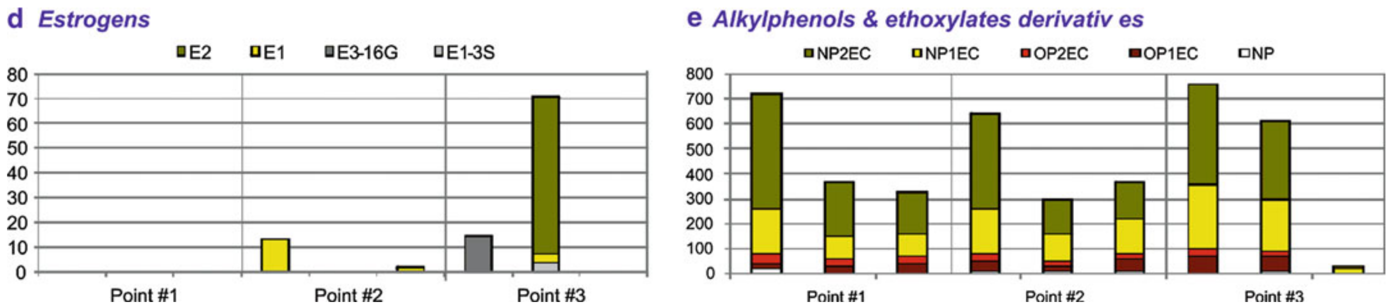


Fig. 10 Mean concentrations in nanograms per liter of micropollutants at the three sampling points; points 1 and 2: river water, point 3: tertiary treated sewage

the river, such as chemical or biological degradation, or adsorption onto sediments, and (2) by the possible existence of some temporal minor water stream reaching the Llobregat River between points 1 and 2, neglected in (1), that might contribute to a higher dilution factor (Q_2). Whereas the second factor would be expected to equally affect all compounds, the former looked more plausible, since it was more compound dependent. Notwithstanding, the mass-flow balance equation could be qualified as a valuable tool to predict downstream concentrations of pollutants if flows and concentrations (river and effluent discharges) occurring upstream were known, and the distance traveled by water was moderate.

5 Conclusions

Most Mediterranean countries are arid or semiarid with mostly seasonal and unequally distributed precipitations. Owing to the rapid development of irrigation and domestic water supplies, conventional water resources have been seriously overexploited. As a result, wastewater reclamation and reuse are increasingly being integrated in the planning and development of water resources in the Mediterranean region, particularly for irrigation. Cyprus, France, Israel, Italy, Jordan, and Tunisia are the only Mediterranean countries to have established national guidelines for the use of reclaimed wastewater. Regional guidelines exist in Spain [4]. The existence of guidelines is necessary for the planning and safe implementation of wastewater reuse for irrigation. It also contributes to a sustainable development of landscape and agricultural irrigation [145]. In Catalonia (El Prat WWTP), the defined reuse project will improve ecological conditions in the lower part of the Llobregat River basin, contribute to reduce the scarcity of water resources in the Barcelona metropolitan area, and help to avoid seawater intrusion into Baix Llobregat delta aquifer. To obtain the required water quality for reuse in many countries, different tertiary treatments are used. There is a variety of tertiary treatments and in general most of them are efficient for removing micropollutants. As illustrated above, there is no optimum tertiary treatment for the complete elimination of organic pollutants from the secondary effluent [130, 146].

In the case study, we examined the impact of a tertiary wastewater recharge on the river water quality by monitoring the occurrence of five classes of contaminants. The campaign was run during the severe drought occurred in 2008 in the lower Llobregat River (NE Spain) which was considered a representative basin of the semiarid Mediterranean area. With the exception of estrogens, being only present in tertiary treated sewage waters at very low concentrations, all the remaining families were detected both in the river and in the tertiary effluents at comparable levels. In general, detected concentrations of the target analytes were similar to or slightly below those reported previously in the Llobregat River and in other Spanish rivers discharging into the Mediterranean Sea. The detection of a broad spectrum of organic pollutants corroborated the heavy impact of contaminant sources in the river such as households, industry, and agriculture.

To get a better appraisal of the relative contribution of the river basin upstream and sewage discharged to the burden of the different contaminants, their respective concentrations and flows should be handled together, especially if one considers the low proportion of the receiving river flow relative to the discharged tertiary effluent (in our case the average ratio was ca. 4:1). For comparison purposes, this can be conveniently addressed using loads (mass-flows), calculated from their respective concentrations and flows. The so calculated loads also serve to provide an estimate of the overall bulk quantities of the different compounds and families.

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Problems and Needs of Sustainable Water Management in the Mediterranean Area: Conclusions and Recommendations

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Abstract The chapter brings a brief overview of problems related to the sustainable water management in the Mediterranean area. It discusses some essential issues, such as (1) working for a culture of water saving, (2) institutional building, and (3) socioeconomic constraints related to the reuse of treated sewage waters outlining short- and long-term actions in several priority areas (drinking water treatment, wastewater treatment, reuse of wastewater, and reuse of sewage sludge).

Keywords Long-term and short-term actions, Mediterranean region, Sustainable water management, Water reuse

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1 General Introduction: Problems and Facts

The Mediterranean Sea is the largest semi-enclosed European sea, characterized by a narrow shelf, a narrow littoral zone, and a small drainage basin especially in the northern part. Today 82 million people live in coastal cities in 21 countries on the Mediterranean rim and by 2025 there will be an estimated 150–170 million people. Today the southern Mediterranean countries account for 32% of the region's population and by 2025 that is expected to have reached 60%. Even though the population growth is slowing down in the area, this will still mean an increase in environmental pressure in the immediate future, especially because the rise in population will be mainly concentrated in the countries in the southern and eastern Mediterranean. The important level of human activity in coastal areas is also leading to serious pollution problems, caused by the large quantities of industrial and urban wastes that are produced and discharged into the sea with a low capacity for self-decontamination and a slow water renewal cycle. Seasonal population pressures are also very high. Over 100 million tourists visit Mediterranean beaches and cities every year and this number is expected to double by 2025. In order to cater for this booming business, natural habitats have been replaced by modern resorts and the extra pollution generated is often dumped untreated into the sea, threatening the equilibrium of entire ecosystem of the region.

The regions included in the Mediterranean basin are among the world areas most suffering of water scarcity in addition to the pollution of freshwater resources. It is estimated that 30 million Mediterranean people live without access to clean drinking water. In the future, tensions on the resources are expected to be particularly high in Egypt, Israel, Libya, Palestinian Territories, and in the Spanish Mediterranean catchment areas (index at 75% or higher), as well as in Malta, Syria, Tunisia, and in some catchments of Morocco (index between 50 and 75%).

Understanding water scarcity and the way to cope with scarcity is not just a matter for water managers or scientists. Water scarcity has a direct impact on citizens and economic sectors that use and depend on water, such as agriculture, tourism, industry, energy, and transport. Water scarcity and droughts also have broader impacts on natural resources at large through negative side effects on biodiversity, water quality, increased risks of forest fires, and soil impoverishment. Ultimately, the shortage of available water may not only have effects on water quality, but also have effects on the ecosystems' integrity, and may result in economic and social disarrangements.

The increased pressure on water resources will cause additional effects on aquatic ecosystems, with some direct and indirect effects. This is particularly relevant since freshwater ecosystems deliver relevant services to human societies. The effects on watersheds are commonly focused on streams and rivers. Hence, there will be effects on morphology (incision and channel simplification), chemistry (higher nutrient and pollutant concentrations), and biological communities (lower diversity, arrival of invasive species, and lower efficiency of biological processes). Regional climate models provide a series of consistent high-resolution scenarios for several climate variables across Europe. Analyses in Mediterranean watersheds consistently suggest that the climate will be significantly hotter and drier, especially in summer. It is foreseen that this will influence both the fate and behavior of pollutants.

Since it is evident that the physical, socioeconomic, and environmental limits of supply-based policies have been reached, future scenarios include implementation of a number of policies based on improved water demand management and policies aimed to increase exploitable potential through improved water and soil conservation, and increased recourse to the artificial replenishment of water tables in arid areas. Alternative scenarios account for potential savings in agriculture (including reutilization of wastewater, reduction of transport losses, and increase in efficiency in irrigation), industry (increase in recycling rate), and domestic water (reduction of transport losses and leaks).

Analyzing potential alternatives and needs indicates that there is not a single and easy solution for water scarcity because multiple causes (or stressors) require multiple solutions. Several options need to be applied when considering the existing resources. In particular for the scenario of climate change, increased demand and decreasing resources must be considered. These options need to consider the delicate coupling between social and natural systems, where each has their share. Both improved technologies and upgraded water management practices are necessary in all sectors where water is used (e.g., agriculture, manufacturing, or tourism). It is essential that the full economic and environmental costs be considered in evaluating the alternatives, where conservation of resources and their quality *at the source* could also be included. The use of decision support systems may be helpful in integrating the multiple actors, as well as in optimizing drought management and mitigation measures.

More relevant options are:

- Working for a culture of water saving and efficiency is essential. This requires an active public awareness from citizens and economic sectors. Potential savings can be stabilized into the future and these savings extended to domestic and agricultural needs. Developing water savings in irrigation, within general planning for the economical needs of the whole territory, is essential.
- Valuing ecosystem services can provide a framework for understanding that societal needs and natural capital are not separated. Public education is critical to achieve the goal of compatible use of water resources and the conservation of our natural heritage.
- Improvement of wastewater treatment (WWT) quantitatively and qualitatively. Any choice of treatment technology performed should rely on those not entailing excessive costs and providing the best environmental practice and option. Furthermore, new and innovative control strategies could be adopted to improve the biological process performance and reach a proper water quality and energy consumption. Adoption of new technologies for wastewater treatment will help to face up these goals. An interesting strategy to improve water treatment along with maintaining power consumption under control is to consider the combination of different technologies (biological and physico-chemical) in a single wastewater treatment plant according to the different effluent characteristics.

- Pilot plant tests and benchmarking of existing works will provide a useful knowledge to help in the choice of the wastewater treatment plant (WWTP) technology and layout. These activities will improve the long-term performance of the new WWT infrastructures.
- Reuse of sewage waters can be considered as an adequate water source for urban, tourism, and agricultural uses. With proper treatment, sewage water can even be used for drinking water. There exist several techniques adequate for the improvement of chemical and microbiological quality that could help to provide these uses. The solutions are linked, however, to available energy; this sometimes becomes the critical limitation. Public perception and cultural issues also need to be evaluated and improved when this source of water is considered. Thus, public consultation would help to early detect future misunderstandings.
- Desalination is a current option to obtain water resources that could provide a source of water that could be considered as independent of potential changes in climate. However, energy needs and costs are high. Consequently, desalination should not be considered the only option.
- Use of groundwaters requires adequate protection of aquifers. Overexploited aquifers affect available water for surficial aquatic ecosystems and may create problems of subsidence and salt water intrusion. Recharging aquifers requires good chemical and microbiological quality of the waters. Some techniques to improve the water quality of underground waters exist, even at the large scale. Recovered groundwater wells can provide additional resources (up to 25 Mm^3 in Catalonia which could be raised to 90 Mm^3 during extreme droughts).
- There are a lot of universities and research centers with international prestige what can provide knowledge and experience to evaluate or assess (during the planning of the actions) the foreseeable effects of the new water projects identified within the UfM to the global change. Furthermore, short- and medium-term monitoring with adequate indicators has to be considered to check the evolution of water bodies and to acquire "in situ" experience for future projects and to assess the impact of the planned "actions."

2 Priority Areas of Action

- Drinking water treatment
- Wastewater treatment
- Reuse of wastewater
- Reuse of sludge

2.1 Drinking Water Treatment

As the world increasingly comes to the realization that a combination of population increases, development demands, and climate change means that freshwater will be in chronically short supply in rich and poor areas of the world alike, there is increasing interest in desalination as a technique for tapping into the vast and infinitely tempting water supplies of the sea. Until recently, widespread desalination for the purpose of general water supply for land-based communities has been limited by its great expense, and it is notable that the area where desalination made by far the greatest contribution to urban water supplies was in the oil-rich and water-poor states around the Persian Gulf. Improvements in the technology of desalination, coupled with the rising cost and increasing unreliability of traditional water supplies, are bringing desalinated water into more focus as a general water supply option with major plants in operation, in planning, or under consideration in Europe, North Africa, North America, Australia, China, and India among others.

However, seawater desalination is also raising significantly the overall energy intensity, potential climate impact, and cost of water. This dramatic upscaling of the industry is occurring against a backdrop of unresolved questions on the potential environmental impacts of large-scale processing. Despite improved technology and reduced costs, desalinated water remains highly expensive and sensitive in particular to increases in energy costs. Our knowledge of impacts is largely based on limited research from relatively small plants operating in relative isolation from each other. The future being indicated by public water authorities and the desalination industry is of ever larger plants that will frequently be clustered together in the relatively sensitive coastal environments that most attract extensive settlement.

Short-Term Actions

- Construction of desalinization plants
- Capacity building (practical issues, operational parameters, control, improving of analytical capabilities)

Long-Term Actions

- Study of long-term environmental impact of desalinization
- Innovative technologies for treatment of concentrates; technology research and technology transfer

2.2 *Wastewater Treatment*

Sewage generation from coastal cities is one of the major pollution problems on the Mediterranean coast. The problem is exacerbated due to the rapid growth of many coastal cities and towns, especially on the southern Mediterranean coast. The sewage collection system is often only connected to parts of the urban population, which leads to direct discharge of untreated wastewater into the sea through other outfalls.

Existing wastewater systems are generally capital intensive and require expensive, specialized operators. Therefore, before selecting and researching in a wastewater treatment technology, an analysis of cost effectiveness needs to be made and compared with all conceivable alternatives. The selection of technologies should be environmentally sustainable, appropriate to the local conditions, acceptable to the users, and affordable to those who have to pay for them. Simple solutions easily replicated that allow further upgrading with subsequent development and that can be operated and maintained by the local community are often considered the most appropriate and cost effective. The choice of a technology will depend on the type of wastewater. In the developing countries usually characterized by high population density and notable shortfall in available water resources, the proper wastewater technology to be adopted under the prevailing local conditions is one of the critical issues which should be well defined.

For the local application of treatment techniques, studies must be undertaken including a detailed risk assessments evaluating microbiological, chemical, and biological factors to identify necessary technologies, uses, and control tools. For regional utilities, this minimum treatment level is expanded to include tertiary treatment. For that, rules and regulations need to be established or adjusted to the new requirements of WHO (2006). Farmers should be involved in the project as they might get benefit from wastewater or sludge reuse as appropriate treated wastewater is a valuable resource that must be utilized and agriculture is given priority for reuse.

The lack of personnel with the appropriate technical and managerial skills for the use of advanced technological tools and implementation of modern management strategies are among the major constraints for achieving the goals of improved wastewater management practices and attaining more efficient wastewater management practices. There is a general necessity to transform the concepts of water efficiency improvement and water saving in industrial applications into implementation policies, programs, and actions on the ground in the countries which are particularly affected by water shortage problems as the arid and semi-arid areas from the South Mediterranean and Middle East Regions.

Technologies available are many and well known, but it has been widely demonstrated that certain industrial wastewaters require the application of innovative treatment technologies. Moreover, any choice performed should rely on those not entailing excessive costs and providing the best environmental practice and option.

Short-Term Actions

- Construction of WWTPs and sewer networks
- Rehabilitation and upgrading of existing WWTP
- Capacity building (practical issues, operational parameters, control, improving of analytical capabilities)

Long-Term Actions

- Projects on integrated management of wastewaters
- Monitoring of water quality and environmental risk assessment
- Development of innovative technologies for wastewater treatment; technology research and technology transfer

2.3 Reuse of Wastewater

The scarcity of water and the need for protecting the environment and natural resources are the main factors leading countries in the Mediterranean region to introduce the reuse of treated wastewater as additional water resource in their national plans of water resource management. The key types of constraints to such practices are:

- *Financial constraints* (related, for example, to high costs of treatment systems and sewerage networks, high operational costs especially for electricity, low prices of freshwater compared with reclaimed wastewater, low user willingness to pay for reclaimed wastewater).
- *Health impacts and environmental safety* especially linked to soil structure deterioration, increased salinity, and excess of nitrogen.
- *Standards and regulations*, which are in some cases too strict to be achievable and enforceable and, in other cases, not adequate to deal with certain existing reuse practices.
- *Monitoring and evaluation* in both treatment and reuse systems, often related to lack of qualified personnel, lack of monitoring equipment, or high cost required for monitoring processes.
- *Technical constraints*, including, for instance, insufficient infrastructure for collecting and treating wastewater, inappropriate setup of existing infrastructure (not designed for reuse purposes), and improper functioning of existing infrastructure.
- *Institutional setup* (especially poor coordination at relevant intra- and intersectoral levels) and lack of appropriate personnel capacity.
- Lack of *political commitment* and of *national policies/strategies* to support treatment and reuse of wastewater.
- *Public acceptance and awareness*, related to low involvement and limited awareness of both farmers and consumers of crops grown with reclaimed wastewater (and/or sludge).

Main area of application of reuse practices are:

- Agriculture and landscape irrigation
- Groundwater recharge
- Direct or indirect potable use

2.3.1 Treated Wastewater Reuse for Agricultural and Landscape Irrigation

Because of the nature of sewage, fears have been expressed about the possible hazards associated with effluent reuse. In assessing these hazards, various pathways for the dissemination of undesirable pollutants have been examined. Two aspects of wastewater reuse in agriculture have become subjects of paramount importance: the possible risks to health and the potential environmental damages. Health considerations are centered around the pathogenic organisms that are, or could be, present in the effluent and the buildup of toxic materials within the soil, and subsequently within plant and animal tissues which might eventually reach the human food chain. The leaching of materials such as nitrates and toxic-soluble chemicals into the groundwater is also a matter for concern. Environmental risks involve the effects of the use of wastewater containing dissolved substances which have deleterious effects on the growth and development of plants.

The reuse of treated wastewater for agriculture irrigation has some advantages, as well as some disadvantages.

Advantages include:

- Source of additional irrigation water.
- Savings of high-quality water for other beneficial uses.
- Low-cost source of water supply.
- Economical way to dispose of wastewater and prevent pollution and sanitary problems.
- Reliable, constant water source.
- Effective use of plant nutrients contained in the wastewater, such as nitrogen and phosphorus.
- Provides additional treatment of the wastewater before being recharged to groundwater.

Disadvantages include:

- Wastewater not properly treated can create potential public health problems.
- Potential chemical contamination of the groundwater.
- Some of the soluble constituents in the wastewater could be present at concentrations toxic to plants.
- The treated wastewater could contain suspended solids at levels that may plug nozzles in the irrigation distribution system, as well as clog the capillary pores in the soil.
- The treated wastewater supply is continuous throughout the year, while the demand for irrigation water is seasonal.
- Major investment in land and equipment.
- Final key question: who will pay the bill?

2.3.2 Treated Wastewater Reuse for Groundwater Recharge

The purposes of groundwater recharge using treated wastewater can be:

- To establish saltwater intrusion barriers in coastal aquifers
- To provide further treatment for future reuse
- To augment potable or nonpotable aquifers
- To provide storage of treated water or to control or prevent ground subsidence

Also, groundwater recharge helps provide a loss of identity between treated water and groundwater. This loss of identity has a positive psychological impact where reuse is contemplated and is an important factor in making treated water acceptable for a wide variety of uses, including potable water supply augmentation.

2.3.3 Treated Wastewater for Direct and Indirect Potable Reuse

Direct reuse of wastewater for potable purposes is clearly limited; indirect reuse for potable purposes takes place constantly and on a worldwide basis. Indirect potable reuse is more acceptable to the public than direct potable reuse as the water loses its identity as it moves through a river, lake, or aquifer. Indirect reuse, by virtue of the residence time in the water course, reservoir, or aquifer, often provides additional treatment and offers an opportunity for monitoring the quality and taking appropriate measures before the water is ready for distribution. In some instances, however, water quality may actually be degraded as it passes through the environment.

Short-Term Actions

- Building of infrastructure for collecting and treating wastewater for reuse purposes
- Institutional setup (improving personnel capacity)

Long-Term Actions

- Planning and development of regional irrigation systems using reclaimed water
- Creation of expertise networks
- Monitoring and evaluation of reuse systems and environmental risk assessment of different reuse options
- Increase of public acceptance and awareness

2.4 Reuse of Sewage Sludge

2.4.1 Sewage Sludge Reuse for Agriculture

Most wastewater treatment processes produce a sludge which has to be disposed of. The reuse of sludge on agriculture has beneficial plant nutrients. Sewage sludge also contains pathogenic bacteria, viruses, and protozoa along with other parasitic helminthes which can give rise to potential hazards to the health of humans, animals, and plants. Thus, sewage sludge will contain, in addition to organic waste material, traces of many pollutants used in our modern society. Some of these substances can be phytotoxic and some toxic to humans and/or animals, so it is necessary to control the concentrations in the soil of potentially toxic elements and their rate of application to the soil. Apart from those components of concern, sewage sludge also contains useful concentrations of nitrogen, phosphorus, and organic matter. The availability of the phosphorus content in the year of application is about 50% and is independent of any prior sludge treatment. Nitrogen availability is more dependent on sludge treatment, untreated liquid sludge and dewatered treated sludge releasing nitrogen slowly with the benefits to crops being realized over a relatively long period. Liquid anaerobically digested sludge has high ammonia-nitrogen content which is readily available to plants and can be of particular benefit to grassland. The organic matter in sludge can improve the water retaining capacity and structure of some soils, especially when applied in the form of dewatered sludge cake.

Other options for sludge reuse include:

- Sewage sludge reuse for biogas production
- Sewage sludge reuse for co-incineration and co-firing
- Biosolids production
- Sewage sludge composting

Short-Term Actions

– Building of facilities for recycling and treatment of sludge
– Capacity building

Long-Term Actions

– Monitoring of sludge quality and environmental risk assessment
– Development of innovative technologies for sludge treatment; technology research and technology transfer

3 Final Conclusions and Recommendations

Scarcity of water resources and needs for protecting the environment and the natural resources are the main factors leading the Mediterranean countries (MC) to introduce treated wastewater as additional water resources in the national plan of water resource management. Analyzing potential alternatives and needs indicates that there is not a single and easy solution for water scarcity because multiple causes (or stressors) require multiple solutions. Several options need to be applied when considering the existing resources. In particular for the scenario of climate change, increased demand and decreasing resources must be considered. It is necessary to integrate water quality in wastewater reuse and to implement a strategy and policy to promote reuse. The selection of the treatment system must be based on the type of the possible reuse. Cost–benefit analysis should include socioeconomic and environmental aspects. Finally, there is also a need of emphasis on community and end users information and education programs with pilot areas for any wastewater reuse program to make clear both the advantages and the disadvantages.

From this it can be concluded that wastewater systems are generally capital intensive and require expensive and specialized operators. This aspect gains special importance when new techniques would be applied, for example, membrane bioreactors, tertiary chemical oxidation treatments, or ultrafiltration and nanofiltration systems for obtaining high-quality reusable water. Therefore, before selecting and researching in a wastewater treatment technology, an analysis of cost effectiveness needs to be made and compared with all conceivable alternatives, taking into account that the use of solar energy in these countries will significantly reduce the operational costs in MC due to their suitability of climate and weather conditions. The selection of technologies should be not only environmentally sustainable, but mainly appropriate to the local conditions, acceptable to the users, and affordable to those who will pay the bill.

Apart from this considerations, some issues remained insufficiently addressed, which give more work for the future, among them we can find water and energy issues: the interactions between water and energy are numerous and are becoming more and more important within the present energy context. It is important that we develop a better understanding of these interactions to improve the sustainability of the global water management.

Key issues to be considered are listed below:

- Working for a culture of *water saving* and efficiency is essential. This requires an active public awareness from citizens and economic sectors. Potential savings can be stabilized into the future and these savings extended to domestic and agricultural needs. Developing water savings in irrigation, within general planning for the economical needs of the whole territory, is essential.
- *Desalination* is a current option to obtain water resources that could provide a source of water that could be considered as independent of potential changes in climate. However, energy needs and costs are high. Consequently, desalination should not be considered the only option. Spanish companies are already leading the construction of new desalination plants in the Mediterranean countries.
- *Reuse of treated sewage waters* can be considered as an adequate water source for urban, tourism, and agricultural uses. With proper treatment, sewage water can even be used, mixed with river or groundwater in some cases, for drinking water. There exist several techniques adequate for the improvement of chemical and microbiological quality that could help to provide these uses. In addition, with the increasing use of wastewater for irrigation will certainly help to decrease the degree of groundwater exploitation thus avoiding seawater intrusion in the coastal areas. However all the solutions are linked, however, to available energy; this sometimes becomes the critical limitation. Public perception also needs to be improved when this source of water is considered. Spanish water companies have a wide experience on building up and managing wastewater treatment plants (WWTP) due to the experience acquired in Spain originated by the implementation of the directive 91/271/CE and WFD (2000/60/EC). It should not be so difficult for Spain to achieve a leadership in this area in a similar way as it occurs in the Mediterranean desalination projects. Other aspects where Spanish water companies will be competitive in the Europe are drinking water supply (due to the implementation of 98/83/EC drinking water directive) and the management of water infrastructures in general, including water for agriculture.

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