Sustainable Sanitation

Practice

EcoSan Club

Issue 14, 1/2013

- Biotechnology for Africa's sustainable water supply
- Water and wastewater management in Morocco
- Overview on water reuse in Egypt
- Wastewater treatment practices in Africa
- What do we require from water biotechnologies in Africa?
- Aquifer Recharge by Treated Wastewaters
- Application of Membrane Bioreactor technology for urban wastewater treatment in Tunisia
- Design considerations for constructed wetlands in dry and hot countries

Selected contributions from the 1st WATERBIOTECH conference, 9-11 October 2012, Cairo, Egypt

partner of:
sustainable sanitation alliance

Impressum

published by / ***Medieninhaber, Herausgeber und Verleger***

EcoSan Club
Schopenhauerstr. 15/8
A-1180 Vienna
Austria
www.ecosan.at

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Aim and Scope / ***Offenlegung der Blattlinie gemäß § 25, Abs. 4 Mediengesetz***

Sustainable Sanitation Practice (SSP) aims to make available high quality information on practical experiences with sustainable sanitation systems. For SSP a sanitation system is sustainable when it is not only economically viable, socially acceptable and technically and institutionally appropriate, but it should also protect the environment and the natural resources. SSP is therefore fully in line with SuSanA, the Sustainable Sanitation Alliance (www.susana.org). • SSP targets people that are interested in sustainable sanitation systems and the practical approach to it. • Articles are published after blind review only. • Sustainable Sanitation Practice is published quarterly. It is available for free on www.ecosan.at/ssp.

Sustainable Sanitation Practice (SSP) hat zum Ziel praxisrelevante Information in hoher Qualität im Zusammenhang mit „sustainable sanitation“ bereit zu stellen. „sustainable“ also nachhaltig ist ein Sanitärsystem für SSP wenn es wirtschaftlich machbar, soziokulturell akzeptiert, technisch als auch institutionell angemessen ist und die Umwelt und deren Ressourcen schützt. Diese Ansicht harmoniert mit SuSanA, the Sustainable Sanitation Alliance (www.susana.org). • SSP richtet sich an Personen, die sich für die praktische Umsetzung von „sustainable sanitation“ interessieren. • Artikel werden nur nach einer Begutachtung veröffentlicht. • Sustainable Sanitation Practice erschient vierteljährlich, kostenlos unter: www.ecosan.at/ssp.

Information on the publisher / ***Offenlegung gemäß § 25 Mediengesetz***

Publisher: EcoSan Club, Schopenhauerstr. 15/8, A-1180 Vienna, Austria • chairperson: Günter Langergraber • website: http://www.ecosan.at/ • scope: EcoSan Club was funded as a non profit association in 2002 by a group of people active in research and development as well as planning and consultancy in the field of sanitation. The underlying aim is the realisation of ecological concepts to close material cycles in settlements.

Medieninhaber: EcoSan Club, Schopenhauerstr. 15/8, A-1180 Vienna, Austria • Obmann: Günter Langergraber • Gegenstand des Vereins: Der EcoSan Club wurde 2002 als gemeinnütziger Verein von einer Gruppe von Personen gegründet, die in Forschung, Entwicklung, Planung und Beratung in der Siedlungshygiene - Sammlung, Behandlung oder Beseitigung flüssiger und fester Abfälle aus Siedlungen - tätig waren und sind. Das Ziel des EcoSan Clubs ist die Umsetzung kreislauforientierter Siedlungshygienekonzepte (EcoSan Konzepte) zu fördern, um einen Beitrag zum Schutz der Umwelt zu leisten.

Editorial

In issue 14 of Sustainable Sanitation Practice (SSP) we publish „Selected contributions from the 1st WATERBIOTECH conference“. The 1st WATERBIOTECH conference was held from 9-11 October 2012 in Cairo, Egypt.

WATERBIOTECH („Biotechnology for Africa‘s sustainable water supply“) is a coordination and support action (Contract No. 265972-KBBE; duration: 1.08.2011 – 31.01.2013) funded within the Africa call of the EU 7th Framework Programme. The action is coordinated by ttz-Bremerhaven (Germany) and has in total 17 partners from 6 European countries (Austria, France, Germany, Italy, Spain, United Kingdom) and 8 African and Arab countries (Algeria, Burkina Faso, Egypt, Ghana, Morocco, Senegal, Tunisia, and Saudi Arabia). More information on WATERBIOTECH can be found on the project website http://www.waterbiotech.eu/.

The first 5 contributions in this issue have been presented at the conference and are directly related to WATERBIOTECH:

1. A general overview of the WATERBIOTECH project
2. An overview on biotechnologies for wastewater treatment in Morocco
3. An overview on current water reuse practices in Egypt
4. Results from a survey from WATERBIOTECH on wastewater treatment practices in Africa
5. Requirements for biotechnologies in Africa which are derived from the survey results

The 3 remaining papers show case studies presented at the conference:

6. A case study on aquifer recharge by treated wastewaters from Tunisia
7. A summary of the results from the PURATREAT project
8. Design considerations for constructed wetlands for hot and dry climates

Besides the authors of the papers we would also like to thank the reviewers of the papers for this special issue, Dr Alberto Figoli (Italy) and Mr Rafael Casielles (Spain), both members of the WATERBIOTECH consortium.

The thematic topic of SSP´s next issue will be „Sanitation Comics“ (issue 15, April 2013). The comic on sanitation can cover one of thefollowing topics: hygiene, urine, faeces, prevention, reuse, recycle, toilets (school toilets, composting toilets, urine diverting dry toilet), waste water, sewer, waste water treatment plant. waste, compost, or any other topics related to sanitation. The comic shall comprise of a number of images and tell a short story. The comic can be in any language and will be translated into English before publishing.

We are still looking for contributions for this very special next issue. We rely fully on your volunteer contributions. For sure, contact details of the artist will be mentioned. The deadline for contributions for issue 15 is 1 March 2013. If you are or know a cartoonist, illustrator, drawer, etc. please contact us as soon as possible.

Information on further issues planned is available from the journal homepage (www.ecosan.at/ssp). As always we would like to encourage readers and potential contributors for further issues to suggest possible contributions and topics of high interest to the SSP editorial office (ssp@ecosan.at). Also, we would like to invite you to contact the editorial office if you volunteer to act as a reviewer for the journal.

SSP is available online from the journal homepage at the EcoSan Club website (www.ecosan.at/SSP) for free. We also invite you to visit SSP and EcoSan Club on facebook (www.facebook.com/SustainableSanitationPractice and www.facebook.com/EcoSanClubAustria, respectively).

With best regards,
Günter Langergraber, Markus Lechner, Elke Müllegger
EcoSan Club Austria (www.ecosan.at/ssp)

Content

Biotechnology for Africa's sustainable water supply

The paper introduces the WATERBIOTECH project „Biotecnology forAfrica´s sustainable water supply" and its midterm progress.

Authors: Sana Arousse, Gerhard Schories

Abstract

Water scarcity, climate change, particular geographic characteristics and limited economic resources have led to a restricted range of choices affordable for African countries to deal particularly with the water issue, as major topic. Polluted water treatment before use has been their almost unique solution to deal with a growing water scarcity. The treatment of water and elimination of pollutants, mainly dissolved organic pollutants, nitrogen and phosphorous compounds, pathogenic organisms, xenobiotics and heavy metals, although itself presents significant challenges, is crucial for environmental considerations and human health. However, most regions in developing countries cannot afford the costs of advanced and specialized treatment systems. WATERBIOTECH presents biotechnology as a useful tool for delivering improved products and processes having the possibility to manage the wastewater economically and effectively around the world.

Introduction / project background

In order to achieve its main objective of presenting efficient and cost effective biotechnological techniques for wastewater treatment, WATERBIOTECH investigated the African water sector based on several influent and tightly linked factors, mainly: climate change, agriculture and food security, and the economic issues.

Climate and water availability in Africa

Water availability and quality, climate, and food security are elements ineluctably linked and with respective influences, hindering human health everywhere and are exceptionally critical in Africa. Africa's water resources are limited, mainly depending on climate factors, essentially rainfalls and weather (temperature, humidity, etc). Even the existing and available quantities of water, are generally subject of low quality hindering people's health and negatively impacting on agriculture. This is of nature to accentuate the environment, health and food stability, in a continent where's registered the highest growth rates of population. In fact, water distribution in major parts of Africa, tightly depends on the climate variable and consequently is characterized by complex patterns and opposite models changing from quasi important rainfalls over the equatorial zone to an extreme aridity in the Sahara. Western Africa and central Africa have significantly greater precipitation than northern Africa, the Horn of Africa and southern Africa. Africa's extreme variability of rainfall is reflected in an uneven distribution of surface and groundwater resources, from areas of severe aridity with limited freshwater resources like the

Key messages:

- WATERBIOTECH is a coordination and support action (Contract No. 265972-KBBE; duration: 1.08.2011 – 31.01.2013) funded within the Africa call of the EU 7th Framework Programme
- The aim and scope of the project is to promote biotechnology as useful, efficient and cost effective technique adaptable to African specific conditions and resources for water - wastewater treatment and reuse particularly for agriculture
- WATERBIOTECH has 17 partners (8 European, 8 African and 1 from Middle East)
- Countries involved:
  - 6 European countries (Austria, France, Germany, Italy, Spain, United Kingdom)
  - 8 African and Arab countries (Algeria, Burkina Faso, Egypt, Ghana, Morocco, Senegal, Tunisia, and Saudi Arabia)
- Initiating and coordinating organization: ttz Bremerhaven (Germany)
- Project website: http://www.waterbiotech.eu/

Sahara and Kalahari deserts in the northern and southern parts, to the tropical belt of mid- Africa with abundant freshwater resources. Northern Africa is the most water-stressed sub-region, with less than 1 percent of the renewable water resources of the continent for an area equivalent to 19 percent of Africa. Freshwater availability will become an even more important issue in the coming decades, for the western Maghreb countries (Morocco, Algeria and Tunisia) where climate change scenarios predict a rise in temperature of between 2° and 4°C this century, accompanied by a reduction in rainfall of up to 20 per cent and increased evapo-transpiration. The driest country is Egypt with 51 mm/year on average, followed closely by Libya (56 mm/year) and Algeria (89 mm/year). The rainfalls are also impacting on the groundwater quantities, from which many African countries are tightly depending. Africa is considering as having the lowest total water supply coverage of any region in the world, with only 62% of the population having access to improved water supply. Indeed, compared to the other continents, Africa's share of global freshwater resources is only about 9%, unequally distributed across the whole continent. These freshwater resources are distributed unevenly across Africa, with western Africa and central Africa having significantly greater precipitation than northern Africa, the Horn of Africa and southern Africa. Most areas receive either too much rain or too little. In parts of the west coast, for example, annual rainfall averages more than 250 cm. The rainfalls are also impacting on the groundwater quantities, from which a lot of African countries are tightly depending. Actually, Africa's freshwater resources average 4050 km^3/year, providing in the year 2000 an average of about 5000 m^3 per capita/year, is significantly less than the world average of 7000 m^3 per capita/year (according to UNEP). At least 13 countries suffered water stress or scarcity in 1990 and the number is projected to double by 2025. The spatial distribution of both surface water and groundwater is uneven, while groundwater is a major source of water in the region, accounting for 15 percent of Africa's total resources. Groundwater is used for domestic and agricultural consumption in many areas, particularly in arid sub-regions where surface water resources are limited. However, areas heavily dependent on groundwater reserves are also at risk of water shortages, as water is extracted far more rapidly than it is recharged. This is the case for Algeria and Libya respectively depending at 60 and 95 percent on groundwater as first source of fresh water.

Water availability, agriculture and food security in Africa

The productivity of agricultural, forestry and fisheries systems depends significantly on the availability of freshwater resources for irrigation and fresh water supply. By seriously affecting crop productivity and food production, in addition to being a necessity in food preparation processes, water plays a critical crucial role in food security. Currently, huge losses due to crop failures arising from droughts are being experienced more frequently than ever before in Africa where one billion people are still undernourished (according to FAO). In sub-Saharan Africa, one of three people - or 236 million (according to FAO) - are chronically hungry, the highest proportion of undernourished people in the total world population. Socio-economic pressures over the next several decades will lead to increased competition between irrigation needs and demand from non-agricultural sectors, potentially reducing the availability and quality of water resources for food. At the same time, during this century, climate change may further reduce water availability for global food production, as a result of projected mean changes in temperature and precipitation regimes, as well as due to projected increases in the frequency of extreme events, such as droughts and flooding. Indeed, the recent IPCC Fourth Assessment Report (IPCC, 2001) indicates that climate change will have significant impact on crop production and water management systems in coming decades, seriously hindering the irrigated agriculture, which represents the bulk of the demand for water in these countries, and which is also usually the first sector affected by water shortage and increased scarcity, inducing a decreased capacity to maintain per capita food production while meeting water needs for domestic, industrial and environmental purposes. In order to sustain their needs, these countries need to focus on the efficient use and management of all water sources.

Water and its economic dimension

The availability and access to freshwater is an important determinant of patterns of economic growth and social development. Freshwater is a necessary input for industry and mining, hydropower generation, tourism, subsistence and commercial agriculture, fisheries and livestock production, and tourism. In Africa, most people live in rural areas and are heavily dependent on agriculture for their livelihoods. The economy is also the major stressor of the environment; for instance, production in the industrial and agricultural sectors contributes to pollution of the air and water and the generation of solid and hazardous wastes. Consumption activities lead to the production of solid waste and create demand for wastewater treatment services. In Africa, the economic development and the water situation are critically linked and both reversely impacted. Most of industries in Africa are polluting without treatment options, mainly because of a lack in financial resources or awareness of availability of affordable technical solutions. The focus in these countries is mainly on building industries and enhancing the economy, while ignoring at a large extent the environmental and ecologic aspect. In the very recent few years, African governments, especially in the northern countries, started begging attention to the water issue; however, no significant actions are taken yet, mainly due to the expensive technologies and knowledge transfer in the water treatment sector.

WATERBIOTECH concept and structure

Biotechnology applied in the treatment of polluted water resources can play an important role in addressing the challenge of water scarcity in developing countries. Biotechnological wastewater treatment methods are governed by aerobic and/or anaerobic micro-organisms or plants which can detoxify dissolved contaminants in water. This allows society to reclaim their resource value. However, many applications of biotechnology have not yet delivered practical solutions or are not widely used due mainly to the lack of information about the potentials and benefits of these technologies as well as the lack of dissemination of solutions adapted to local conditions. WATERBIOTECH is an initiative that will contribute to cope with water scarcity in Africa by providing access to relevant stakeholders in Western, Eastern and Northern Africa to knowhow in biotechnologies, good practices and management solutions adapted to their local conditions for the sustainable management of polluted water resources. The targeted countries of the present Coordination Action will be Algeria, Burkina Faso, Egypt, Ghana, Libya, Morocco, Senegal, and Tunisia. The idea is to disseminate best practices jointly with all the requirements and the strategy necessary for the implementation of selected biotechnologies specifically assigned to local regions within the targeted countries, getting inspired from time to time, from former projects carried on the field. Relevant actors that will benefit from this action will be farmers, providers of sewage treatment services, authorities and decision makers, specialized scientific community, local communities, and general public who live in water stressed areas. The integrated approach of WATERBIOTECH takes into consideration that different aspects influence the availability to water resources and only a holistic vision can provide effective solutions to enhance water management in African countries. Environmental and health concerns, as well as socio-economic aspects such as households income, water consume patterns, irrigation methods or interests in water resources of different stakeholders must be taken into account in the proposal of solutions. For that reason, WATERBIOTECH will provide solutions based on a deep analysis of the current situation in the targeted countries, and cost-benefit analyses developed during the project considering the specific requirements of local regions. WATERBIOTECH outputs will enhance the decision making process by providing guidelines and materials that support stakeholders to implement cost-effective and sustainable solutions adapted to the reality in their regions. These outputs will:

- Provide recommended biotechnologies adapted to specific local conditions
- Make available an investment decision tool based on cost-benefit analyses of biotechnological best practices
- Facilitate the exchange of information between biotechnology providers and end users in order to enhance market opportunities in biotechnology and their operation services
- Train relevant stakeholders in technical and non-technical aspects required for the implementation of recommended biotechnologies
- Raise awareness on the necessity of sustainable and environmentally sound technologies for development
- Show examples of good practices in demonstrative activities of implemented technologies.

The project is structured in a way that all partners contribute promptly based on their knowledge and expertise within a particular task. All efforts are conjugated to ensure a complete partnership with a specific knowledge transfer via innovative schemes and methodologies. The exchange of expertise between European and Arab-African countries (partners) is of nature to promote the development and uptake of innovative and adapted methods, highlighting and focusing on the role of biotechnology in water treatment. The exchange of experiences and know-how will be very fruitful for WATERBIOTECH.

The project approach is not only technical oriented, but is widely based on training, knowledge transfer, awareness and involvement rising of the whole addressed community members, which is of nature to enhance the process of water resources management. More precisely, the project conceive a research co-ordination platform formed by an expert network to define, organize and manage common initiatives and to co-ordinate, assess and guide suitable research activities, of biotechnological methods adapted to the socio-economic and environmental conditions of the targeted developing countries for the treatment of polluted water before use, for agricultural, industrial and domestic activities. The contribution of each of the parties will be integral to the enforcement of the project, with a process of external consulting and participation through panel discussions and workshops with all relevant interested, will be thereby developed. Locally, regular consultations with different sectors and participatory processes in training the local interest groups will be held during the last half of the project period through national and international workshops.

Project progress

WATERBIOTECH's was launched in August 2011 and its activities effectively started after the kick off meeting held in Tunis, Tunisia in September 2011. Actually, the project already went through its first half period time marked by the organization of the WATERBIOTECH first international conference held in October 2012 in Cairo, Egypt. The midterm stated on the steady progress towards the project objectives for which all fixed milestones have been reached on time with no hindering delays. In fact, the project subdivided into several work packages, presents a clear overview of the activities performed and the other still to be. The activities were initiated by WP1 within which a geographic segmentation of Africa based on the regional water availability as key differentiator factor have been completed. This led to a classification of the targeted countries within homogeneous regions in order to provide adapted solutions in subsequent work packages. Each region has been assigned with a regional representative within the consortium. These targeted regions have been then characterized with regards to legal and institutional, socio-environmental and economical aspects. Moreover, the work package team assessed the general obstacles potentially hindering any innovative technological implementation in the targeted regions, taking into account technological and non technological obstacles. These activities have been followed by the activities of WP2 where an evaluation of existing water treatment biotechnological practices within the targeted countries has been performed. This evaluation from both a socio-economic and an environmental perspective has been based on questionnaires applied across the targeted countries by the respective national African partners. As a result of the evaluation, best practices within the targeted countries have been identified. In parallel with this task, technical and non-technical requirements for the implementation of innovative water treatment biotechnologies in the specific targeted regions identified in WP1 have been defined. Cost-benefit analyses of the investments to implement selected best practices have been as well developed under this work package in order to assess costs of implementing biotechnological practices previously selected against the total expected benefits.

The work at this stage (Month 15 of the project's period) is enhanced with the third work package already started with an identification and assessment of potential innovative biotechnologies for the sustainable water management in the targeted countries. Taking into account the most applicable innovative biotechnologies as well as the best existing practices identified, this work package team will assign to each of the targeted regions identified in WP1 suitable practices and biotechnologies adapted to their characteristics. The cost-benefit analyses developed under WP2 will be extended to the biotechnologies selected in WP3.

A database of biotechnology suppliers for WW treatment has been elaborated identifying the regional suppliers, who can allow the concrete implementation of water treatment biotechnologies. This database will be part of the guideline for the implementation's process of the biotechnologies for water treatment to be developed. The dissemination activities are accompanying all project's steps and phases. Demonstration and training workshops to be organized at month 24, 26 and 29, respectively corresponding to July, September and December 2013, will be the main outcomes of the technology transfer work package (WP4) followed by the final WATERBIOTECH's international conference to be held in Marrakech, Morocco in January 2014.

Conclusion

The technical part of the project will focus on promoting the role of biotechnology in water treatment practices in Africa. A deep assessment on water treatment biotechnologies and their adaptability to the African situation will be performed during the project. Innovative water treatment biotechnologies such as activated sludge systems including membrane bioreactors and sequencing batch reactors, trickling filter systems, rotating contactors or constructed wetlands as well as conventional methods such as stabilization ponds will be evaluated in order to provide adapted solutions to specific selected regions based on previous analyses of the socio-economic an environmental situation of the targeted countries. Special attention is paid – apart from purification performance - to decentralised installations considering energy efficiency and energy supply by renewable energy sources. The regional approach of WATERBIOTECH intends to cover the lack of know how in regions that face water scarcity consequences, but also to guide latest research achievements in biotechnology to solve local problems. Innovation is a key source of competitive advantages, a multiplier of economic activity, employment and development. Investments in human capital cannot only foster the creation of innovation but also, and most importantly in rural areas, the assimilation of innovation that is often produced elsewhere. For that reason, capacity building on biotechnology is an essential factor in WATERBIOTECH initiative. Strengthening local capacities will be on focus during the project workshops, in which guidelines and recommendations developed under the project activities will be presented to decision makers and other relevant stakeholders. The achievement of the project results will contribute to a better understanding of the African requirements for promoting research and innovation and how these aspects can boost the economical situation of the continent and therefore improve the living conditions of their inhabitants.

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Water and wastewater management in Morocco: Biotechnologies application

This paper presents a review about water and wastewater management in Morocco with a special focus on the application of biotechnologies for wastewater treatment.

Authors: Laila Mandi, Naaila Ouazzani

Abstract

This paper presents an overview about water and waste water management in Morocco. The main problems related to the availability of water resources and their preservation from the pollution are described. Moreover, a detailed description of the different efforts done in Morocco in recent years to overcome the technical, economical and organizational problems of water and wastewater management and to catch up the considerable delay regarding sanitation and recovery of treated wastewaters has been reported too. Regarding sewage treatment, the stabilization ponds called also natural lagoons are considered as the most appropriate biotechnology to treat the increasing flows of domestic wastewater in Morocco. The treatment of sewage through natural stabilization ponds was recommended in early 2000 by the National Sanitation Master Plan (SDNAL), particularly because of its low investment and operating costs. However, other sophisticated biotechnologies such as aerated activated sludge have been chosen for big cities due to the large areas that would be required for.

Water resources

Morocco, located in the Northwest of Africa, has an area of 710,850 km² with two long coastlines of 3,500 km of which over 500 km of the Mediterranean and about 3,000 km over the Atlantic. Morocco has approximately a population of about 30 million inhabitants, and its climate is marked by sharp contrast in temperatures between the Mediterranean climate and desert. Like many countries in the world, Morocco is faced with the problem of the development and sustainable management of its water resources. These scarce resources, marked by wide geographical disparities and highly sensitive to vagaries of the weather, come under heavy pressure due to demand resulting from population growth, improved living conditions and the implications of economic development. To support this trend, there is a need for sustained development of water resources in quantity and quality in order to ensure widespread access to drinking water and reduce inequality between regions, notably between urban and rural areas (ADB, 2006). Insufficient rain and droughts are fairly frequent. In 1982, Morocco received less than 60% of the long-term mean rainfall. In 1994, on the other hand, 6 of 11 hydrological basins in Morocco had more than 50% deficit in their water balance (Doukkali, 2005). The average annual precipitation in Morocco is 150 billion m³, varying year by year between 50 billion m³ and 400 billion m³. Annual evaporation is, on average, 121 billion m³. Of the remaining 29 billion m³, about 22 billion m³ of water are technically and economically exploitable (Benbiba, 2010).

Water consumption and needs

The Moroccan exploitable resources are comprised of 18 billion m³ of surface water and 4 billion m³ of

Key messages:

- Preserving and protecting water resources, natural environment and sensitive areas
- Reducing vulnerability to the risks associated with water and adaptation to Climate Change
- Continuing regulatory and institutional reforms related to water resources management
- Biotechnologies such as stabilization ponds could be considered as efficient means for wastewater treatment relying on low cost technology with minimal maintenance
- Modernization of information systems and capacity building and skills is a necessity
- Making direct use of wastewater R&I for socio-economic development in the medium and long term

groundwater (Benbiba, 2010). In Morocco, the volume of water available per inhabitant per year, an indicator of a country's wealth in terms of water, is about 1000 m³/capita/year (Figure 1). Scarcity is often defined as starting from this point.

At present, the available water varies between 180 m³ per capita per year for the areas known to be poor in terms of water resources (Souss-Massa, Atlas South, and Sahara) and 1800 m³ per capita per year for areas of the basin of Loukkos, Tangier and Mediterranean Coast, known to be relatively rich (ADB, 2006). It is probable that the water resources per inhabitant will reach around 700 m³ per capita per year towards 2020 (Figure 2).

At this time, about 14 million inhabitants, i.e. almost 35% of the total population of the Kingdom will have less than 500 m³ per capita per year at their disposal. Water scarcity is thus becoming a permanent situation that can no longer be ignored when drawing up strategies and policies concerning water resources management in Morocco.

The water resource mobilization for the different social and economic uses is grossly done according to the following distribution (Figure 3).

Underground waters contribute for meadows of 32% to satisfy needs in drinkable water and about 31% for the agricultural needs. We have to mention that agriculture mobilizes the great part of water resources. It is a choice and strategy that Morocco took since the years 60 and concretely there was the construction of a great number of dams from this date. The vision was ensuring the food security and reducing the dependence with foreign countries.

The main producer of drinkable water in Morocco is the national office of drinkable water (ONEP) that was created in 1972. The production increases and the capacity of current production exceed 55 m³/s. This organism practices equally the distribution in the cities. For big cities, There are offices that do the distribution and some ones were privatized (Lydec in Casablanca, Amendis in Tangier, Redal in Rabat). The service rate in urban area exceeds currently 95%. In rural area, it exceeds now 91% while it was only about 14% in 1992 (Makhokh and Bourziza, 2011). For irrigation water and concerning the big hydraulic (irrigation from big dams), there are agricultural offices that sell water to the farmers. The big irrigated perimeters (Haouz,

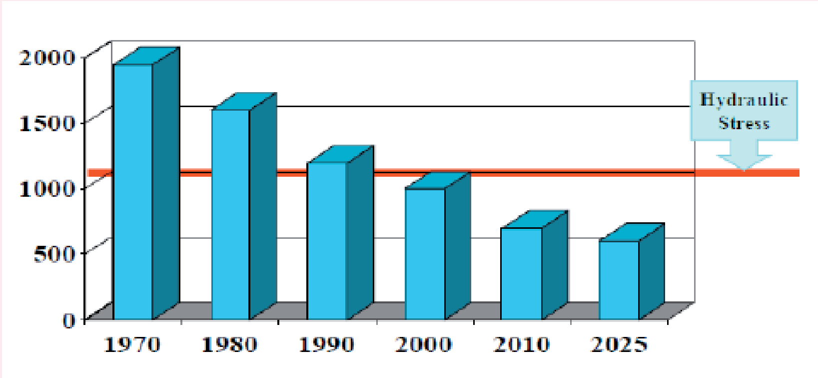


Figure 1: Water resources in Morocco in m³/year per inhabitant

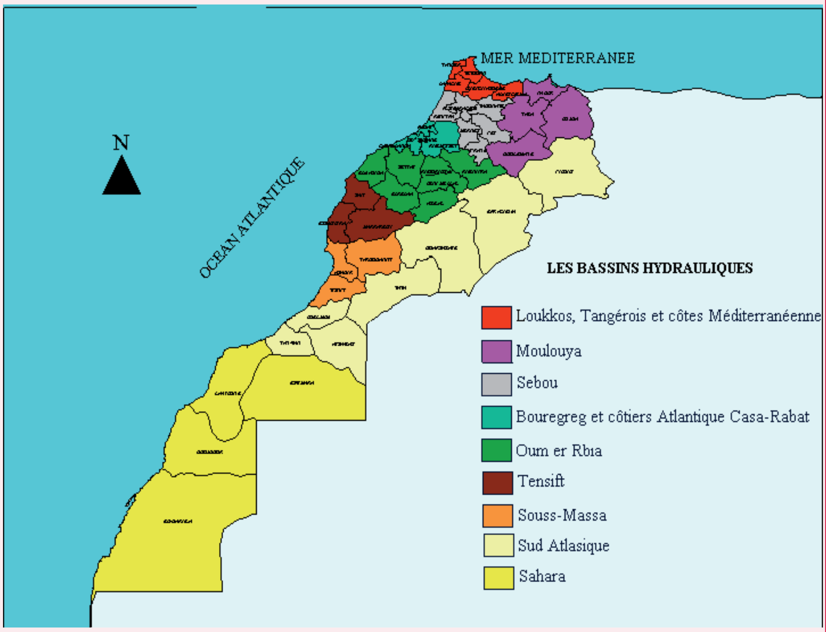


Figure 2: Geographical Distribution of River Basin in Morocco (Jemalli and Kefati, 2002)

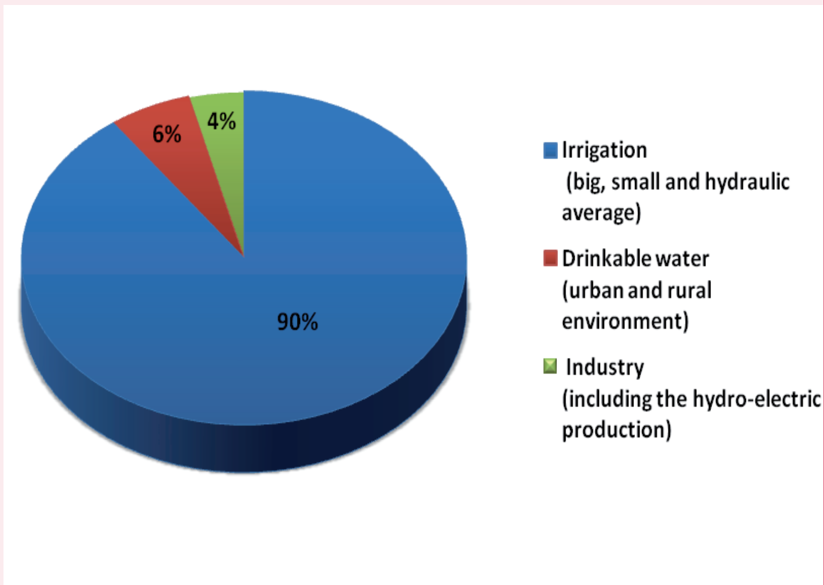


Figure 3: Water resources consumption in Morocco

Tadla, Gharb...) have fixed water allocations according to master plans and according to hydraulic state in dams. The other industrial uses of water concern mainly the industry food processing, sweets and the oilseeds. Regarding superficial waters mobilization, a sustained effort regarding construction of dams was undertaken since 1967 until our days. Up till now, the kingdom counts 128 large dams with a capacity of nearly 17 billion m^3. The dam's edification continues currently with a rhythm of a 1 dam/year. From 1984 and considering the dry years that succeeded on the kingdom, a construction policy of hill dams (small dams) was adopted (Benbiba, 2010). Several infrastructures were realized to satisfy the local population's needs. Concerning balances between areas, 13 water transfer systems with a total length surpassing 1000 km were set up. The total mobilized flow is about 200 m^3/s. For underground waters, a sustained effort about increasing resources is undertaken since a linear of 100 km/years including wells and drillings is realized. The park of well and drilling allows having 2.87 billion m^3/year.

Morocco is characterized by limited rainfall and strong geographical inequality of the rainfall. To address this situation a New National Water Strategy was launched in 2009 covering the period from 2010 to 2030.This policy is based on the main following strategic objectives (Benbiba, 2010):

- Management of water demand and water efficiency
- Management and supply development
- Preservation and protection of water resources, the natural environment and sensitive areas
- Reducing vulnerability to the risks associated with water and adaptation to Climate Change
- Modernization of information systems and capacity building and skills
- Improvement of the institutional, legal and financial framework

Legal framework

In 1982, the organizational aspect was marked by the establishment of the regional directions of hydraulic (DRH). The foundation of such act is the management and the water planning within watersheds. In fact, and before this date, prevailed the vision of a planning water resources by project. This date coincided with a drought cycle (1981-1986) that incited the authorities to review the old institutional aspect.

In 1995, and after the economic and social development of Morocco, the DRH structure and some old texts showed their limits and became not adapted to the general Moroccan context. It is the 10/95 law that entered in force and this with a new approach and concepts.

The federal principles of this law are as follows (Royaume du Maroc, 1995):

- The public domain of water: all water availability is part of the public domain of the state.
- The unity of water resources management: the domain and scale of study is the watershed.
- The recognition of the economic value of water: adoption of the principles operator payer and polluter payer.
- The creation of the basins agencies: spaces consultation between the different actors and water users. They are autonomous organisms taking care of the water management within the watershed.
- National and regional solidarity: among the objectives of basins agencies creation, the instauration of mechanisms of solidarities and notably about water transfers between basins.

The new structures coming from the 10/95 law are as follows:

- The higher water consul: for the elaboration of the general orientations regarding management and planning water at the national scale.
- The river basins agencies: for a rational and collective use of water integrating the different actors.
- The water provincial commissions: spaces consultation grouping together the local groups, the different provincial services and the professional associations.

The application Decree (No 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 recognized as treated wastewater. The use of raw wastewaters is thus prohibited and banished. The Norms and Standards Committee (NSC) that comes under the National Environment Council is setting objectives for the quality of receptor medium (quality norms). The NSC is made up of representatives from all relevant ministerial departments. Among the suggested norms, there is a project relating to quality standards of wastewaters designed for irrigation, which specifies the bacteriologic, parasitic, and physical-chemical parameters. These Standards for the reuse of wastewater apply to all types of irrigation water, including treated wastewaters. The aim of the standards is to protect environment and health.

Institutional organization

The institutional organization of water domain in Morocco is based on 3 levels, including the major stakeholders involved in the water domain (Figure 4).

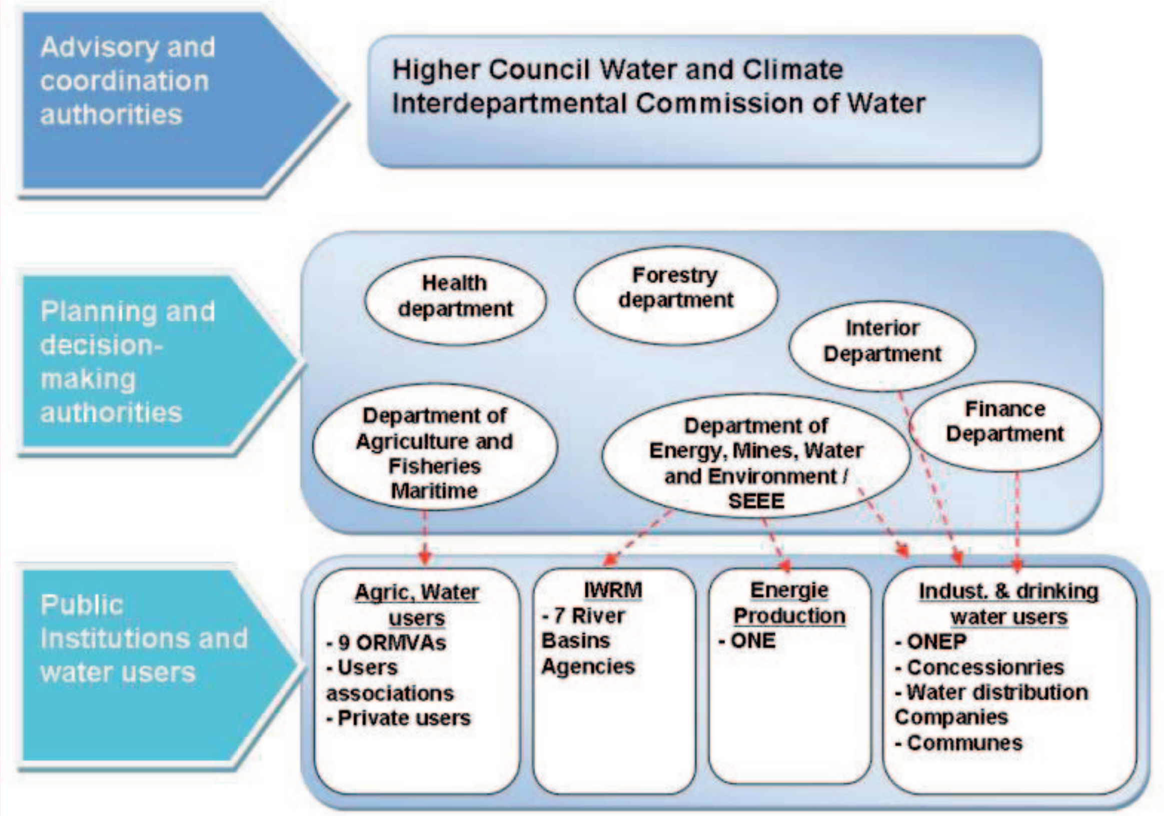


Figure 4: Main institutional stakeholders (Ouassou et al., 2005)

Among the inherent problems to the water management in Morocco, is the multiplicity of the stakeholders:

- River Basins Agencies: they are 9 throughout the country for managing the main hydraulic basins of the kingdom.
- ONEP (national office of drinkable water): principal producer of drinkable water in Morocco, it is equally distributor in small and average cities.
- Distribution offices: autonomous organisms taking care the drinkable water distribution in the big cities of the Kingdom.
- Municipalities: concerning the hydraulic aspect, they take care of watering gardens and green spaces.
- Rural Towns: drinkable water of the rural populations
- ORMVA (agricultural offices): responsible for the management of the big irrigated perimeters of the Kingdom.
- DPA (provincial delegations of agriculture): management of the small and average hydraulic.
- ONE (national office of electricity): principal producer of the electric energy including the hydraulic origin (merged actually with ONEP)
- Waters and forests administration: are taking care of the watersheds development.
- The provincial health delegations: health aspect, hygiene, Diseases including the ones from hydrous origin

The experience of the past showed that a lot of contentious situations in some areas occurred because of the insufficiency coordination between the different actors. In order to endow the country with a national strategy in water domain, the higher water consul was created in 1989 by his majesty the king Hassan II. This institution aims to coordinate the different departments intervening in the water sector. Thus, the big orientations concerning water policy are studied in this council. The studies of master plans are equally approved within this institution which is presided effectively by the King of Morocco (Mandi, 2012).

At a regional scale and in accordance with the 10/95 law promulgated in 1995, it is the river basin agency that plays the role motor since the water management is done in a collective way with the different actors and partners within this institution.

Wastewater treatment and reuse

The actual total volume of sewage discharged in Morocco is estimated at about 750 million m³ (Figure 5); 48% of these waters are discharged into the rivers or applied to land; the rest is discharged into the sea without any treatment. The pollutant load from wastewater is estimated at around 131,715 tons of organic load, 42,131 tons of nitrogen and 6,230 tons of phosphorus. Most of the wastewater produced by inland towns is reused, mainly as raw or insufficiently treated wastewater, to irrigate about 7500 hectares.

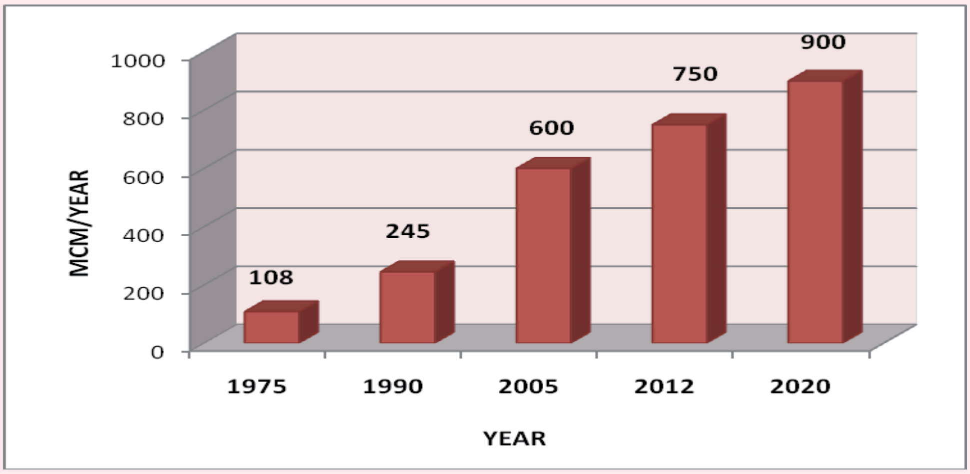


Figure 5: Evolution of total volume of sewage discharged in Morocco

The lack of wastewater treatment before reuse in inland cities was translated into the exposure of the local population to waterborne diseases and the degradation of superficial and ground water resources.

There is a considerable delay regarding liquid and solid sanitation in the construction of purification stations and recovery of treated wastewaters. In urban area, the global rate of connection to the sewer system is about 70% which means that about 4, 5 millions of urban populations are not connected to the network and are using autonomous purification systems (ADB, 2006). For the purification systems, Morocco has 100, of which more than half are not functional for many reasons: technical, financial and human (Mandi, 2012). Such situation shows not only delay that the country combined in this domain, but also contamination risks about receiver environment in general and water resources in particular. Therefore, to protect water resources and reduce the pollution, a national sanitation and sewage program is developed to improve sewerage collection, the treatment of both industrial and domestic wastewater, and increase the reuse.

In 2005, the National Sanitation Program was approved that aims at treating 60% of collected wastewater and connecting 80% of urban households to sewers by 2020 (Royaume du Maroc,2008). The main objectives of this program are:

- Achieve a rate of 80% as connection to sewerage.
- Improve sewerage collection,
- Reduce pollution caused by wastewater at least 60%.
- Catch up the delay in the sanitation domain.
- Treat both industrial and domestic wastewater,
- Increase the reuse.

The support of the EU in the national sanitation program of Morocco reaches € 90 million.

Application of water biotechnologies in Morocco

Since 1950s, Morocco has introduced Biotechnologies for urban wastewater treatment in some medium and small centres; these biotechnologies were: activated sludge, trickling filter and biodisc. Activated sludge plants were not operated regularly due to lack of maintenance and the high energy costs needed for continuous operation. The need to allocate necessary funds to sustain the operation of these plants was not properly understood by local governmental boards. Most of the new plants built in the 1990s employ extensive technologies, such as stabilization ponds or natural lagoons, high rate algal ponds and sand filter. Until 1993, there were 55 wastewater treatment plants serving small centres and medium-sized cities. Only 18 of them were operating normally while 31 plants were out of service and the remaining six were not connected to the sewerage network since pumping stations could not be financed for various reasons: inadequacy of the treatment system to local conditions, design defect structures, lack of maintenance, management issues (lack of budget, lack of competent technical staff), lack of planning short and long term (Mandi, 2000). The treatment of sewage through natural stabilization ponds was recommended in early 2000 by the National Sanitation Master Plan (SDNAL), particularly because of its low investment and operating costs. However, other treatment techniques such as activated sludge have been chosen for larger cities (Marrakech, Fez,) due to the large areas that would be required for using stabilization ponds. Actually Morocco has more than 100 wastewater treatment plants with more than 77% are natural lagoons (Figure 6).

The biotechnologies that are most known by the key actors acting in the field of sanitation in Morocco are natural lagoons (Figure 7). This biotechnology is considered as the most appropriate biotechnology to treat the increasing flows of domestic wastewater in Morocco.

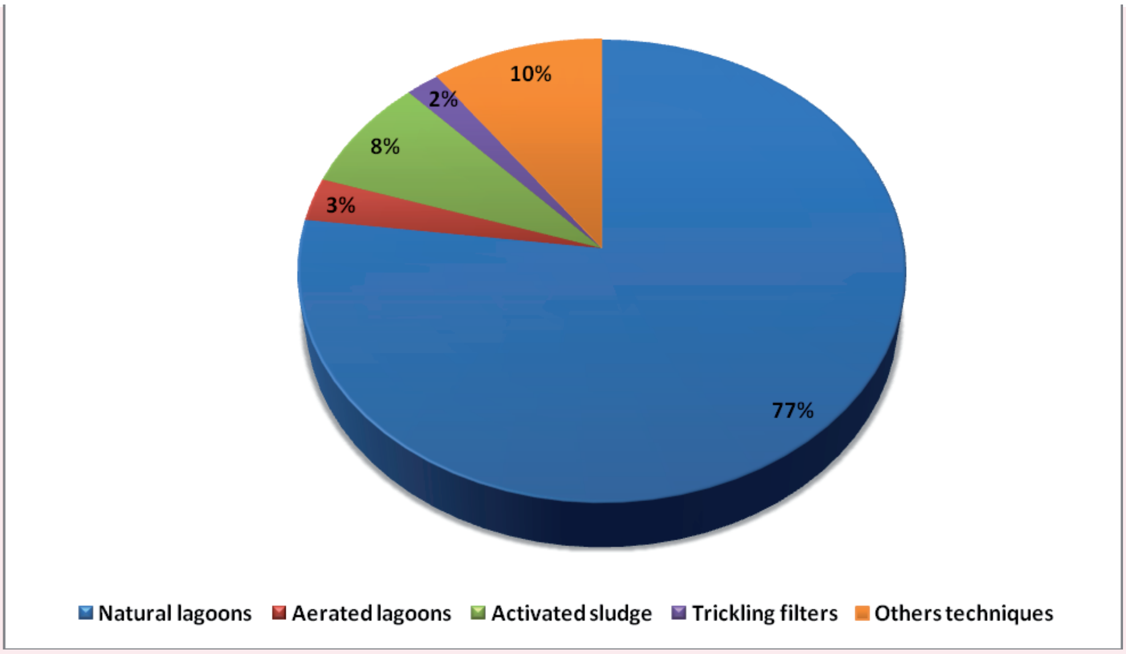


Figure 6: Distribution of different kind of wastewater treatment technologies existing in Morocco (Makhokh and Bourziza, 2011)

The natural lagoons or stabilization ponds have in general 1-4 m deep (sealed with plastic film) slowly traversed by sewage. Most installations consist of a chain of consecutive basins. Given that the total residence time of sewage in such a facility is several weeks, these systems required a relatively high surface area. The long-term retention of wastewater disposal promotes the effective inactivation of pathogens excreted with faeces. The mortality process is promoted by UV radiation and a net increase in pH caused by algae during active photosynthetic periods.

Examples

Over the past 20 years, the WSP systems have emerged and have proven their effectiveness as economic treatment process requiring little maintenance, especially in hot climates for both small as for large municipalities and cities (Ouazzani et al, 1995). This technology was developed by the ONEP in small and medium centres since 1970 and it represents now more than 80% of the biotechnologies used in Morocco (Picture 1). The ONEP have recommended the choice of Waste stabilization ponds in the majority of the directory schemes of sanitation realized for lot of small and medium cities in Morocco.

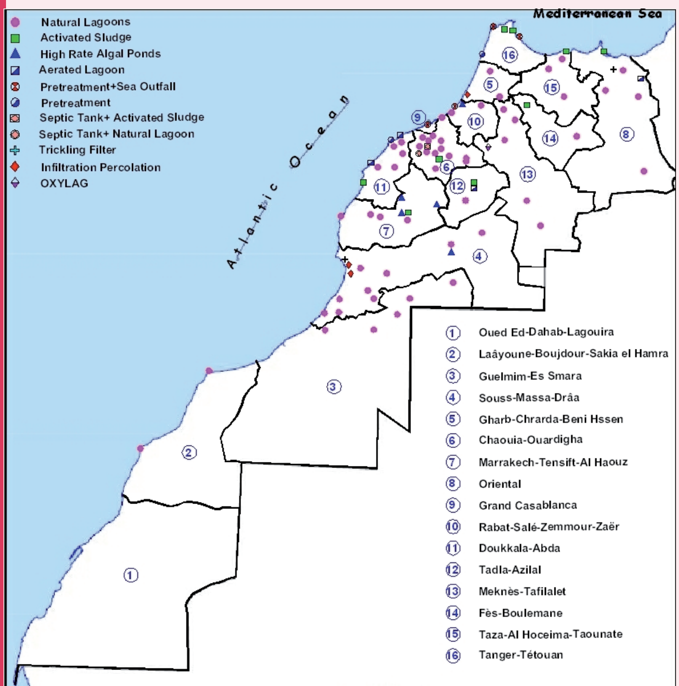


Figure 7: Geographical distribution of wastewater treatment Biotechnologies in Morocco

Picture 1: Natural lagoons for wastewater treatment plant of the Saada commune (Peri-urban area of Marrakech city)

Picture 2: Largest aerated lagoons in Morocco (Oujda city)

In Morocco, combined pond system that integrate aerated lagoons and storage reservoir have been successfully applied in Oujda city (Picture 2) and produces a high quality effluent meets the non-restricted irrigation WHO guidelines. The first important water reuse project in Morocco was implemented in 1997 in Ben Slimane city (Picture 3), where 5600 m^3/day of wastewater is treated by anaerobic, aerated lagoons, facultative, and maturation ponds consecutively. The disinfected effluent (0 helminth eggs/l, <20 CF/100 ml) is used for golf course irrigation during the summer (for an average volume of reused water of 1000 m^3/day).

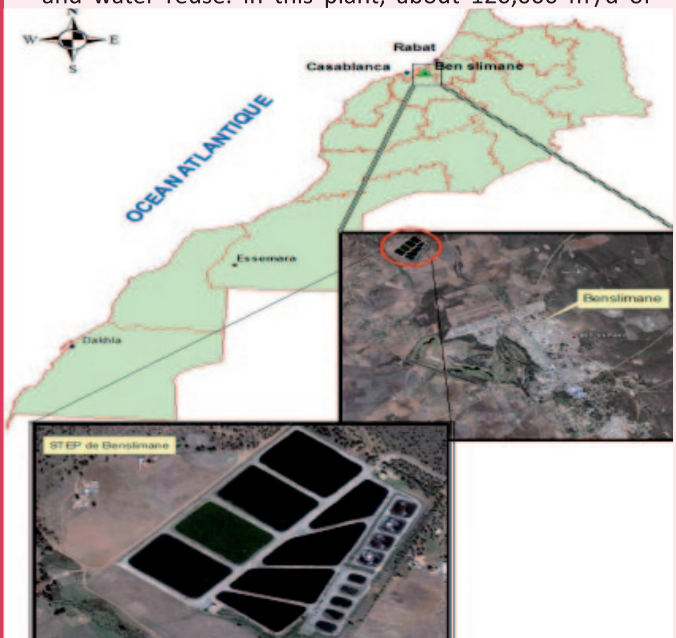
The new Marrakesh wastewater treatment plant (WWTP), which started treating wastewater in 2011 (Picture 4), is considered as the first WWTP in North Africa to integrate wastewater treatment, biogas recovery from sludge, electricity &heat cogeneration, air treatment and water reuse. In this plant, about 120,000 m^3/d of wastewater are treated in four stages: 1) pre-treatment 2) primary treatment in sedimentation tank 3) secondary treatment that employs activated sludge (i.e. aerobic sludge treatment) 4) tertiary treatment, which consists of microfiltration by sand filter and disinfection by ultraviolet lamp units. This last process raises the effluent quality of the wastewater before it is reused for irrigation of golf courses. The electricity consumed by the plant is around 30 GWh/year while the electricity generated by four cogeneration units with a power of 862 kW is in total about 10.5 GWh/year. About more than 70% of the treated water coming from this WWTP are re-used recreational purposes (golf course, palm grove, etc.). The treatment and re-use of Marrakech's wastewater is a milestone in sustainable development, which made significant progress towards attaining Morocco's national target of 60% effluent treatment by 2020.

Barriers for wastewater treatment biotechnologies

In spite of the progress achieved by Morocco in term of wastewater treatment, the majority of the biotechnologies for domestic wastewater treatment implemented in several small and medium communities still not functional for the following reasons (Mandi, 2012):

Financial

- Expensive cost of electricity.
- Absence of equipment and maintenance.
- Lack of an adequate budget for plant maintenance and operation.
- Lack of coordination between different contributors in the management of the plants.



Picture 3: Wastewater treatment and reuse project of Benslimane City (El Haite, 2010)

Picture 4: Marrakech Aerobic WWTP with sludge digestion and methane production for energy cogeneration

- The cost of further steps of treatment such as disinfection in order to have an effluent that meet the irrigation water standards.
- The need of additional cost for sludge treatment technologies in parallel to water treatment plants.

Social

- Some plants have been built on the limits of some cities which threaten the future of these plants because of extension of housing and the nuisance of odours.

Capacity building (experienced staff)

- The sewage treatment plants do not operate satisfactorily and, in most cases, treated wastewater discharges exceed the legal and/or hygienically acceptable maxima. This is attributed to the lack of adequately trained staff with the technical skills to operate these plants.
- Trained operators are a prerequisite for the control and monitoring of all treatment and reuse operations.

Regulation

- In several cases, the outflow of wastewater treatment systems does not meet specified quality standards, either because standard operating procedures are not followed or because technically qualified personnel to control and monitor plant operations is unavailable.
- Wastewater authorities are unable to monitor continuously operational parameters in the treatment plant.

Conclusion

Morocco is situated in arid area and has been faced to several water management problems. In addition of the aridity of climate, the heterogeneity of water resources distribution, repetition of drought related to climate change reduce the potential of water resources. In addition, the discharge of urban and industrial wastewater increases the threat of water pollution and reduces of the availability of water resources. In spite of big effort on water availability and water supply for the growing population in Morocco, and even though legislative, organizational upgrading of the management of water sector, a big delay has to be catch up in the sanitation and wastewater treatment. The high costs of conventional treatment processes have lead national authorities to search for creative, efficient and environmentally sound ways to control water pollution. The development of simple and cost effective water treatment biotechnologies such as Stabilization ponds and aerated lagoons is particularly interesting for Morocco. These processes that use relatively more land and are lower in energy and operational costs are becoming attractive alternatives for many wastewater treatment applications especially in Moroccan small communities. In the case of inland large cities where the land becomes extremely expensive and/or not available, the use of sophisticated biotechnologies such as activated sludge is recommended. Biotechnologies could be considered as useful tool to manage wastewater economically and effectively in Morocco as well as in other African countries. Moreover, the big challenge is to overcome all the socio-economic and institutional barriers that hindering their development.

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Overview on water reuse in Egypt: Present and Future

Use of treated wastewater is of tremendous potential importance to Egypt, particularly for restricted irrigation and forest trees.

Authors: Hussein I. Abdel-Shafy, Mona S.M. Mansour

Abstract

Egypt is extremely dependent on the River Nile, in fact, 97% of the population lives on 4% of the land, around the river Nile. The renewable water resources were 2189 m^3/capita/year in 1966. This will drop to 500 m^3/capita/year by the year 2025. Effluents from municipalities have been used in Egypt since 1922 in sandy soil areas like Al-Gabal Al-Asfar and Abou-Rawash. Currently, 0.7 billion m^3 (BCM) per year of treated wastewater is being used in irrigation, of which 0.26 BCM is secondary treated and 0.44 BCM is primary treated wastewater. The agricultural sector is utilizing about 86% of the available water supplies. The drainage water from agriculture is collected, by an extensive drainage network. Currently about 5.5 BCM of drainage water are being reused after mixing with fresh water. This amount is expected to increase up to 9.6 BCM by the year 2017. In general, treated wastewater use is of tremendous potential importance to Egypt.

Introduction

Egypt is an arid country, which covers an area of about 1,001,450 km^2 of which only 4% is occupied by its population. The population has tripled during the last 50 years from 19 million in 1947 to about 83.5 million in 2012 of whom about 99% are concentrated in the Nile Valley and Delta. The population is estimated to be about 100 million by the year 2025 (Abdel-Lateef et al., 2011). One of the important issues in the future is to redistribute the population over a larger area. To reach this objective, it is essential to reclaim new lands in order to provide the required food for the new communities. The agriculture requirements exceed 80% of the total demand for water (Abdel-Shafy and Aly, 2002). In view of the expected increase in water demand from other sectors, such as municipal and industrial water supply, the development of Egypt's economy strongly depends on its ability to conserve and manage its water resources.

Meanwhile, water demand is continually increasing due to population growth, industrial development, and the increase of living standards. The per capita share of water has dropped dramatically to less than 1000 m^3/capita, which is classified as „Water poverty limit“. It is projected that the value decreases to 500 m^3/capita in the year 2025 (Abdel-Wahaab, 2003) (Figure 1).

Most cultivated lands are located close to the Nile banks, its main branches and canals. Currently, the inhabited area is about 5.3 million ha and the cultivated agricultural land is about 3.3 million ha.

The per capita crop area declined from 0.17 ha in 1960, 0.08 ha in 1996 to about 0.04 ha in 2012 (World Bank, 2007, Abdel-Shafy and Aly, 2002). The sharp decline of the per capita of both cultivated land and crop area resulted

Key factors:

- It is essential to reclaim new lands in order to provide the required food for new communities.
- Nowadays the per capita share of water has dropped to 633 m^3/capita/year, i.e. below the water poverty limit
- The per capita crop area declined from 0.168 hectare in 1960 to 0.042 hectare in 2012.
- The capacity of wastewater treatment plants has increased by 10 times in the last two decades.
- Separating sewage and industrial wastewater is important for safe water reuse.
- Currently there are 63 man-made forest trees irrigated with water reuse in Egypt

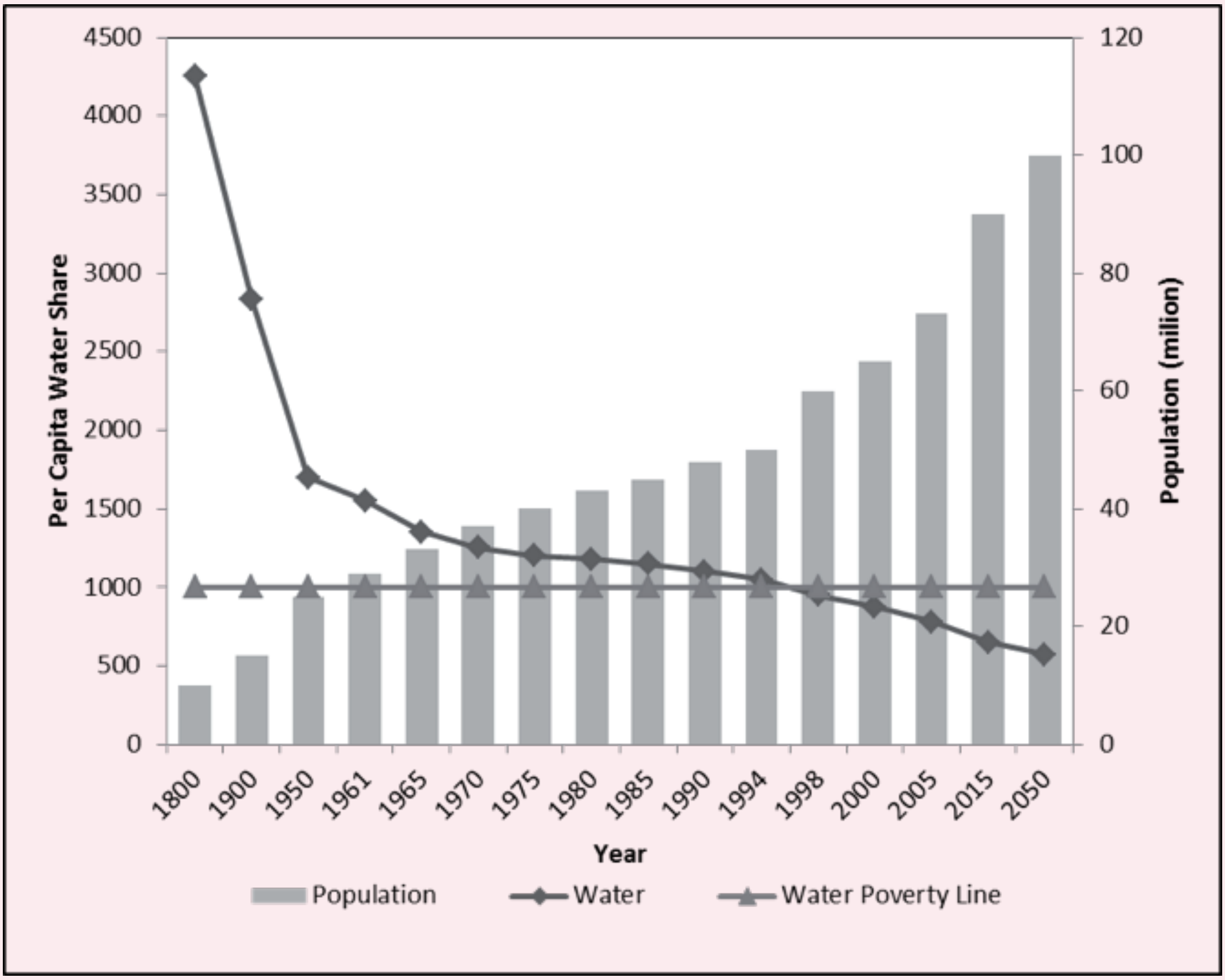

Figure 1: Population growth and per capita water share in Egypt in m^3/year (Abdel-Wahaab, 2003).

in the decrease of the per capita crop production. This affects directly the food security at individual, family, community and country levels (World Bank, 2009).

Water resources

Water resources in Egypt are limited to the following resources:

- Nile River
- Rainfall
- Groundwater in the deserts and Sinai and
- Desalination of sea water

Each resource has its limitation on use, whether these limitations are related to quantity, quality, space, time, or use cost. The following is a description of each resource.

Nile River Water

Nile water budget is 55.5 x 109 m^3/yr to Egypt and 18.5 x109 m^3/yr to Sudan according the agreement between both countries in 1959 (Dijkman, 1993). The Nile River inside Egypt is completely controlled by Aswan dam in addition to series of seven barrages between Aswan and the Mediterranean Sea. Egypt relies on the available water storage of Lake Nasser to sustain its annual share of water. Nile water comprises about 91.5% of the total fresh water supply and the 97% of renewable water supplies in Egypt (Abdel-Shafy and Aly, 2007). Water supplies and demands in Egypt are given in Table 1.

Rainwater

Rainfall in Egypt is very scarce, with an annual average of 12 mm (Abdel-Shafy et al. 2010). The mean annual rainfall ranges from 0 mm/year in the desert to 200 mm/year in the north coastal region (Figure 2). Rain falls only in the winter season in the form of scattered showers (Abdel-Shafy and Aly, 2002). Rainwater is concentrated on the northern part of the country. It is between 150 - 200 mm, and decreases gradually to the south reaching around 24 mm.

The maximum total amount of rain does not exceed 1.8 billion m^3 (BCM) per year. At present, the average annual amount of rainwater that is effectively utilized for agricultural purposes is about 1 BCM per year (Abdel-Shafy et al. 2010).

Table 1: Water supplies and demands in Egypt in BCM per year (Abdel-Shafy and Aly, 2002).

	1990	2000	2025
Water supplies			
Nile water	55.5	55.5	57.5
Ground water:			
- in the Delta and New Valley	2.6	5.1	6.3
- in the desert	0.5		
Reuse of agricultural drainage water	4.7	7.0	8.0
Treated sewage water	0.2	1.1	2.4
Management and saving wasted water	-	1.0	-
Total	**63.5**	**69.7**	**74.2**
Water demands			
Agriculture	49.7	59.9	61.5
Households	3.1	3.1	5.1
Industry	4.6	6.1	8.6
Navigation	1.8	0.3	0.4
Total	**59.2**	**69.4**	**75.6**

Groundwater

In the western desert, groundwater is non-renewable fossil origin and occurs in the geological layers of the Nobian limestone. It supplies the New Valley's Oasis. It has been estimated that about 200,000 BCM of fresh water are stored in this aquifer. The water is at the depth of 60-100 m around the area of East-Oweinat (NWRP, 2005).

In Sinai groundwater is mainly encountered in three different water-bearing formations: i) the shallow aquifers in northern Sinai, ii) the valley aquifers, and iii) the deep aquifers. The shallow aquifers in the northern part of Sinai are composed of sand dunes that hold the seasonal rainfall (heavy storms), which helps to fix these dunes. The annual rainfall on Sinai varies from 40 mm to 200 mm/year. Although most of the shallow aquifers are renewable, only 10 to 20% of the deep aquifers are renewable by rainfall and flash floods. The aquifers in the coastal area are subject to salt-water intrusion. The total dissolved solids in this water range from 2,000 to 9,000 ppm which can be treated to reach a suitable salinity level to be used for irrigating certain crops (Abdel-Shafy and Aly, 2002).

The total groundwater abstraction in the western desert is 0.5 BCM/year and in Delta, Sinai and New Valley is estimated to be 5.1 BCM/year .

Desalination of Sea Water

Desalination of seawater in Egypt has been given low priority. The reason is due to the cost of treating seawater which is high compared with other sources, even the unconventional sources such as drainage reuse (El-Kad and El-Shibini, 2001; Abou Rayan et al. 2004). The future use of such resource for other purposes (agriculture and industry) will largely depend on the rate of improvement in the technologies used for desalination and the cost of power. The amount of desalinated water in Egypt now is in the order of 0.03 BCM/year.

Non-conventional water resources

Non-conventional water resources include:

- the renewable groundwater aquifer in the Nile basin and Delta
- the reuse of treated sewage water
- the reuse of treated agricultural drainage water

These recycled waters cannot be added to Egypt's fresh water resources. The renewable Groundwater Aquifer in the Nile Valley and Delta was estimated at about 500 BCM but the maximum renewable amount (the aquifer safe yield) is only 7.5 BCM. The existing rate of abstraction in regions is about 4.5 BCM/year, which is still below the potential safe yield of the aquifer (WHO, 2005).

Sanitation in Egypt

Existing situation

Sanitation services in Egypt are less developed than water supply services. At present, there are more than 323 wastewater treatment plants in the country. The capacity of wastewater treatment plants has increased by 10 times in the last two decades. The existing capacity is 12 million m^3/day. Length of wastewater collection networks / sanitation pipelines increased from 28,000 km in 2005 to 34,000 km in 2010 (Abdel-Kader and Abdel-Rassoul, 2010).

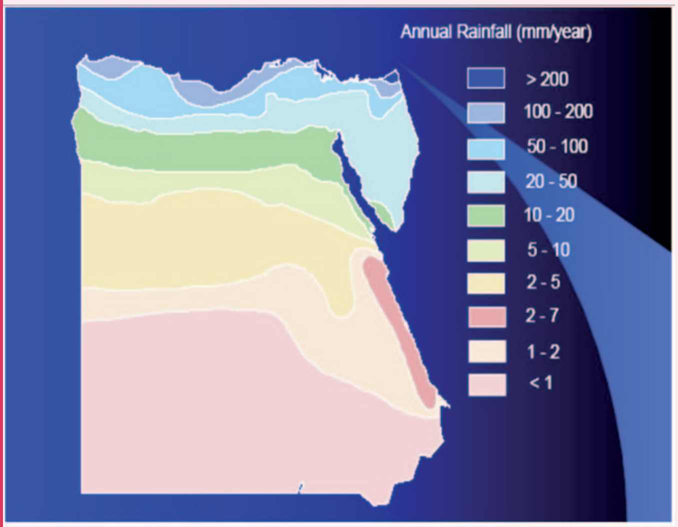

Figure 2: Annual rainfall in Egypt (Abdel-Shafy et al., 2010)-

Urban coverage with improved sanitation gradually increased from 45% in 1993 to 56% in 2004, reaching 100% in urban and 40% in rural areas by the end of 2012. The low coverage in rural sanitation results in serious problems of water pollution and health conditions due to the discharge raw domestic wastewater directly into the waterways (MWRI/USAID, 2000).

Wastewater treatment technologies

Wastewater treatment aims at the removal of biodegradable organic compounds, suspended and floatable material, nutrients and pathogens. However, the criteria for wastewater treatment intended for reuse in irrigation differ considerably. While it is intended that pathogens are removed to the maximum possible extent, some of the biodegradable organic matter and most of the nutrients available in the raw wastewater need to be maintained.

The main criteria affecting selection of the technology are:

- Availability of land
- Skilled labour
- Cost for operation and maintenance
- Power supply
- Performance efficiency
- Implementing costs.

The low-cost treatment systems that can be implemented in Egypt include:

- Up-flow Anaerobic Sludge Blanket
- Modified septic tank
- Stabilization Ponds
- Constructed Wetlands
- Rotating Biological Contactor

Recent studies indicated that it may not be possible, due to economic reasons, to provide sewerage facilities for all residents of rural and peri-urban areas, either now or in the near future. Therefore, the decentralized wastewater treatment facilities are the best solution (MWRI/USAID, 2000; Abdel-Shafy and Aly, 2007; MED WWR WG, 2007).

Why wastewater reuse?

Compared to freshwater in water-stressed regions, treated wastewater (TWW) reuse is considered a beneficial and attractive option for several reasons:

- Prevent surface water pollution, if the wastewaters were discharged into rivers or lakes
- Postpone potentially more costly water supply approaches (storage, transfer, or desalination schemes).
- Eliminate the need for costly and complicated wastewater treatment processes. In particular the removal of nutrients (i.e. nitrogen and phosphorus) is unnecessary
- The quantity of TWW generated will rise with population and increased industrial activity.
- Potential non-agricultural uses for TWW include industrial cooling; landscapes irrigation; fire fighting and toilets flushing in non-residential buildings.
- For agriculture, TWW can be mixed with fresh water, and can be used to grow non-food crops in the desert areas, where it would otherwise serve no useful purpose (i.e. it enables horizontal expansion with little or no cost, at least with respect to two key inputs – land and water).
- The nutrients in TWW reduce the need for applying chemical fertilizers, thereby reducing costs and environmental problems associated with run-off of such chemicals.
- Where well planned, TWW can serve as an environmentally superior alternative to disposing of wastewater in the desert, the sea, or other water bodies.
- Soil Aquifer Treatment provides the potential to recharge TWW to groundwater, thereby supplementing fresh water supplies for irrigation and other purposes, while storing water without evaporation losses or the risks associated with dams. Meanwhile, many contaminants in the effluent, including suspended solids, nitrogen, phosphorus, heavy metals, bacteria, viruses and other microorganisms are reduced or removed through an inexpensive process.

However, there are risks, which refer to the quality of TWW which can be summarized as follows:

- Health risks resulting from human exposure to pathogens in inadequately treated wastewater. These risks affect farm workers, processors of agricultural products and the consumers.
- Contamination of soils and plants through introduction of harmful chemicals.
- Groundwater pollution from infiltration of contaminated source water.

Reuse of Treated Wastewater

The increasing demands for domestic water due to population growth, improvement in living standards and the growing industrial sector will increase the total amount of wastewater available for reuse as an important source. The major issues include public health and environmental hazards as well as technical, institutional, socio-cultural and sustainability aspects.

The future policy for using sewage water can be summarized as follows:

- Increase the amount of secondary treated wastewater use from 1.1 BCM/year by 2000 to 4.5 BCM/year by 2017 (Abdel-Shafy and Aly, 2007);
- Limit the use of treated wastewater to cultivated non-food crops such as cotton, flax, and trees (Abdel-Wahaab, 2003);
- Separate 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 (Abdel-Shafy et al., 2003);.

Reuse of treated wastewater in agriculture

Sewage Water

Currently, Egypt produces an estimated 5.5–6.5 BCM of sewage water per year. Of that amount, about 2.97 BCM per year is treated, but only 0.7 BCM per year is utilized for agriculture (0.26 BCM is undergoing secondary treatment and 0.44 BCM undergoing primary treatment), mainly in direct reuse in desert areas or indirect reuse through mixing with agricultural drainage water (Abdel-Shafy and Abdel-Sabour, 2006).

Treated wastewater (after primary treatment) has been in use since 1922 in agriculture (Gabal-Al-Asfar farm: ca. 1,200 ha). Yet, experience of large scale, planned and regulated reuse project is still limited. Large scale pilot projects (ca. 80,000 ha) are in East Cairo, Abu-Rawash, Sadat City, Luxor, and Ismailia. In the meantime, most of the sewage water drained to the agricultural drains is actually reused in one way or another (indirect reuse) (Abdel-Shafy and Aly, 2002; Abdel-Wahaab, 2003). This practice has been accelerated since 1980 as tremendous potential importance to Egypt.

Agricultural Drainage

The amount of water that returns to drains from irrigated lands is relatively high (about 25 to 30%). This drainage flow comes from three sources; tail end and seepage losses from canals; surface runoff from irrigated fields; and deep percolation from irrigated fields (partially required for leaching salt). None of these sources is independent of the Nile River. The first two sources of drainage water are considered to be fresh water with relatively good quality.

The agricultural drainage of the southern part of Egypt returns directly to the Nile River where it is mixed automatically with Nile fresh water which can be used for different purpose downstream. The total amount of such direct reuse is estimated to be about 4.07 BCM/year in 1995/96. In addition, it is estimated that 0.65 BCM/year of drainage water is pumped to the El-Ibrahimia and Bahr Youssef canals for further reuse (Abdel-Shafy and Aly, 2007). Another 0.235 BCM/year of drainage water is reused in Fayoum while about 0.65 BCM/year of Fayoum is drained to Lake Qarun. Moreover, drainage pumping stations lift about 0.60 BCM/year of Giza drainage from drains to the Rossita Branch just downstream of the delta barrages for further downstream reuse.

Drainage water in the Delta region (Figure 3) is then emptied to the sea and the northern lakes via drainage pump stations. The amount of drainage water pumped to the sea was estimated to be 12.41 BCM in 1995/96. This decreased and will continue to decrease in the future according to the development of the reuse of agricultural drainage water.

Regulation of Agricultural Drainage Reuse

The regulation includes the following measures:

- Increasing the reuse of drainage water from about 5.5 BCM/year to 7.0 BCM/year by year 2014 and to 9.6 BCW/year by year 2017 with average salinity of 1170 ppm (Abdel-Lateef et al., 2011). This could be achieved through implementing several projects to expand the reuse capacity at different areas. Main future projects include El-Salam canal project (Figure 4), El-Omoom and El-Batts drainage.
- Improving the quality of drainage water especially in the main drains.
- Separating sewage and industrial wastewater collection systems.
- 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.

Figure 3: Main drainage Canal in the Delta region, Egypt (Abdel-Wahaab, 2003).

- Updating and implementing an integrated information system for water quality monitoring in drains.
- 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.

Guidelines for the reuse of treated wastewater in agriculture

Irrespective of the treatment level the Egyptian Code prohibits use of TWW for the production of vegetables eaten raw or cooked, export-oriented crops (i.e. cotton, rice, onions, potatoes, and medicinal and aromatic plants) as well as citrus fruit trees, and irrigating school gardens, respectively (EEAA, 2000).

Plants and crops irrigated with treated wastewater are classified into three agricultural groups that correspond to three different levels of wastewater treatment. The Code further stipulates conditions and restrictions for type of crops, irrigation methods and health protection measures for farm workers, consumers, and those living on neighbouring farms.

The Code classifies wastewater into three grades (designated A, B, and C), depending on the level of treatment it has received (Table 2) and specifies the maximum concentrations of specific contaminants consistent with each grade, and the crops that can,

Figure 4: Crossing El-Salam Canal with Suez Canal through a siphon.

and importantly cannot, be irrigated with each grade of treated wastewater (Table 3).

- Grade A represents advanced or tertiary treatment that can be attained through upgrading the secondary treatment plants to include sand filtration, disinfection and other processes.
- Grade B represents secondary treatment performed at most facilities serving Egyptian cities, townships and villages. It is undertaken by any of the following techniques: activated sludge, oxidation ditches, trickling filters, and stabilization ponds.
- Grade C is primary treatment that is limited to sand and oil removal basins and use of sedimentation basins.

Forest trees irrigated with treated wastewater

In 14 governorates and 2 districts, with more than 30,000 ha of marginal desert land allocated, 63 forests are growing thanks to the irrigation with the effluents of WWTPs, whose designed daily discharge is about 1.9 million m^3/day (Abdel-Shafy et al., 2003). The cultivated area is about 5,000 ha (FAO, 2005) and the fallow land area is about 25,000 ha. An overview is presented in Figure 5.

Wastewater reuse constraints

The main constraints facing use of treated wastewater are:

- Financial constraints (related to high treatment costs and sewerage networks)
- Health impacts and environmental safety linked to soil structure deterioration, increased salinity and excess of nitrogen

Table 2: Requirements for treated wastewater reused in agriculture (in mg/l)

Treatment Grade requirements		A	B	C
Effluent limit values for BOD ans Suspended Solids (SS)	BOD_5	<20	<60	<400
	SS	<20	<50	<250
Effluent limit values for faecal coliform and nematode cells of eggs (per liter)	Faecal coliform count (2) in 100cm^3	<1000	<5000	Unspecified

Excerpted from: „Egyptian Code for the Use of Treated Wastewater in Agriculture.“ February 2005

Table 3: Classification of Plants and Crops Irrigable with Treated Wastewater

Grade	Agricultural Group	
A	G1-1: Plants an trees grown for greenery at touristic villages and hotels	Palm, Saint Augustin grass, cactaceous plants, ornamental palm trees, climbing plants, fencing bushes and trees, wood trees and shade trees.
	G1-2: Plants and trees grown for greenery inside residential areas at the new cities.	Palm, Saint Augustin grass, cactaceous plants, ornamental palm trees, climbing plants, fencing bushes and trees, wood trees and shade trees.
B	G2-1: Fodder/ Feed Crops	Sorghum sp
	G2-2: Trees producing fruits with epicarp.	On condition that they are produced for processing purpose such as lemon, mango, date palm and almonds.
	G2-3: Trees used for green belts around cities and afforestation of high ways or roads.	Casuarina, camphor, athel tamarix (salt tree), oleander, fruit-producing trees, date palm and olive trees.
	G2-4: Nursery Plants	Nuresry plants of wood trees, ornamental plants and fruit trees
	G2-5: Roses & Cut Flowers	Local rose, eagle rose, onions (e.g. gladiolus)
	G2-6: Fiber Crops	Flax, jute, hibiscus, sisal
	G2-7: Mullberry for the production of silk	Japanese mulberry
C	G3-1: Industrial Oil Crops	Jojoba and Jatropha
	G3-2: Wood Trees	Caya, camphor and other wood trees.

Excerpted from: „Egyptian Code for the Use of Treated Wastewater in Agriculture.“ February 2005

- Standards and regulations (too strict to be achievable and enforceable).
- Low sanitation coverage
- Large-scale centralized treatment facilities are often discharge the produced wastewater into receiving water bodies
- Lack of political commitment and of national policies/strategies to support treatment and reuse of wastewater
- Public acceptance and awareness, related to limited awareness of both farmers and consumers of crops grown with reclaimed wastewater (and/or sludge)
- Consequently, reuse of water is a lost opportunity, as wastewater is either buried away in cesspools, or discharged into receiving water bodies
- In Egypt many people remain suspicious of reuse since they are uncertain of the quality of treated water.

Conclusions and recommendations

1. The use of treated wastewater should be considered an integral component in country's national water strategic plan.
2. Wastewater management should change from the regional sewerage systems to decentralized wastewater treatment facilities.
3. Decentralized systems will increase the opportunities for localized reclamation/reuse of treated wastewater.
4. Separation of industrial effluent disposal systems, provision of adequate treatment facilities to those communities connected to sewer systems.
5. Search for simple cost-effective treatment technology, horizontal expansion based on reuse of treated sewage. This will increases the coverage of sanitation systems.
6. Awareness of the health risks involved with direct or indirect contact with the water.

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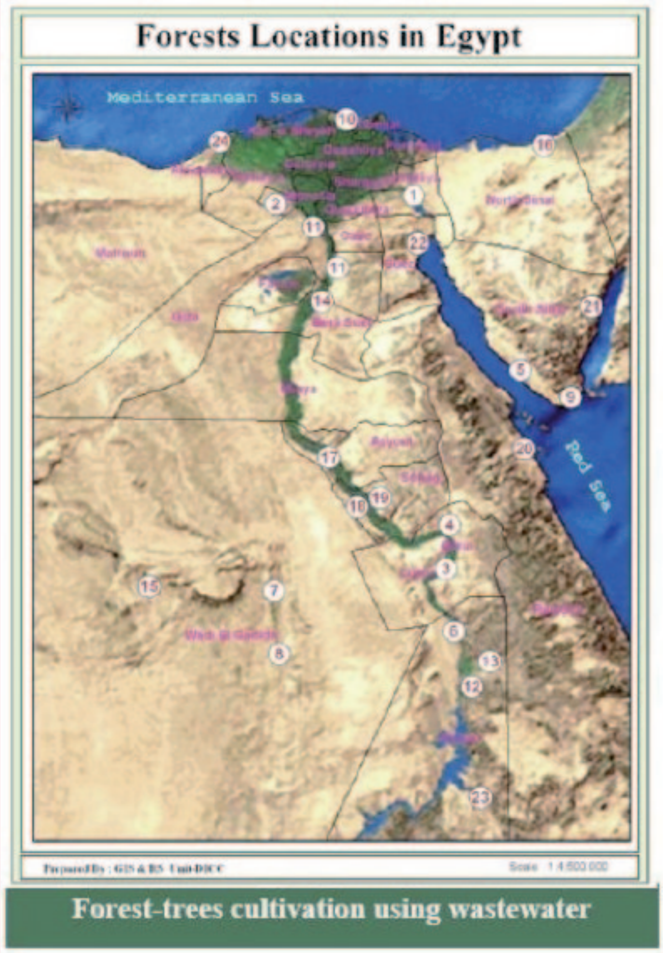

Figure 5: Locations of manmade forests in Egypt (Abdel-Wahaab, 2003).

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Wastewater treatment practices in Africa - Experiences from seven countries

This paper presents the treatment plants existing in Africa; it discusses the types of processes applied, the required treatment performance per country and the main challenges hindering their performance as well as the reuse of the treated wastewater.

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Abstract

In this paper, existing wastewater treatment practices in 7 African countries, i.e. Algeria, Burkina Faso, Egypt, Ghana, Morocco, Senegal and Tunisia, are reported. Data were collected by questioning wastewater treatment plants managers as well as treated wastewater users in 2012. This study showed that 0.2 to 63 L/d/person of wastewater are treated in these countries, with the higher levels obtained for North Africa. Technically, treatment plants (mostly activated sludge and waste stabilization ponds) deal with high organic loads, uncontrolled input, power cuts and increasing wastewater flow rates. Poor operation and maintenance (O&M), in part caused by the lack of funds, high energy costs and lack of re-investments, is also a serious reported issue. Consequently, treatment plants often deliver insufficient effluent quality, which negatively affects the environment and acceptability of stakeholders towards the treated water. Other challenges, such as water availability, long-term impacts, financial and social constraints, affecting the reuse, are also discussed.

Introduction

The coverage with improved sanitation in the different target countries is presented in Table 1. In the 3 Sub-Saharan African (SSA) countries (Burkina Faso, Ghana, Senegal), sanitation coverage ranges between 34 and 72 % for combined improved sanitation and shared/public toilets. This contrasts significantly with the situation in North Africa (Algeria, Egypt, Morocco and Tunisia) where levels are noticeably higher (70-100 %), with limited use of shared facilities. The other side of sanitation is to ensure a proper disposal of the wastewater (including faecal sludge) being generated. One objective of WATERBIOTECH project has been to evaluate the existing technologies for wastewater treatment in the target countries, looking at the types of processes implemented, their efficiency, compared with the standards values, and the current outcomes of the treated water.

Materials and Methods

On the course of this activity, three different questionnaires were prepared (in English, French and Arabic). This paper focusses on the data obtained through interviews in 2012 of key stakeholders, with Questionnaires 2 and 3. Q2 aimed at collecting information on the functionality

Key findings:

- At least 7 out of 10 wastewater treatment plants are either waste stabilization ponds or activated sludge. Treatment plants allowing simultaneous production of biogas are not common.
- The amount per inhabitant of wastewater entering a treatment plant ranges from less than 0.2 L/d/person in Ghana to 63.2 L /d/person in Tunisia.
- Treatment plants face challenges such as high organic loads, uncontrolled waste input, power cuts, increasing wastewater flow rates, poor O&M, high energy costs and lack of re-investments.
- Treatment performance expected from treatment plants in Africa is sometimes barely achievable technically (e.g. 0.05-0.1 mg/l of phosphorus in Tunisia).
- Poor treated wastewater quality, inadequate infrastructure, poor institutional linkages, stringent regulations, limited public/farmers acceptance and awareness and low willingness to pay for this resource are among the top challenges currently faced by target African countries in reuse of treated wastewater.

Table 1. Sanitation coverage in the different target countries[1]

	Burkina Faso	Ghana	Senegal	Algeria	Egypt	Morocco	Tunisia
Urban	*50* (37)	*19* (73)	*70* (19)	*98*	*97* (3) [85]	*83* (14)	*96*
Rural	*6* (10)	*8* (43)	*39* (10)	*88*	*93* (7)	*56* (6)	*52*
Average	*17* (17) [< 5]	*14* (58)	*52* (14)	*95* [86]	*95* (5)	*70* (11) [<60]	[82]

[1] The value in italic is the coverage with improved sanitation (i.e. toilet facility). Between parentheses is given the share of shared/public toilets; between brackets the percentage of households connected to the public sewer (when reported) is given, (JMP, 2012).

The values reported in Table 1 do not necessarily: 1) mean that the systems reported are operational; 2) imply proper treatment and disposal of the wastewater produced. Statistics do not reflect the real situation (which is expected to be much worse) (UN, 2006).

Table 2: Treated wastewater amounts[1]

	Ghana	Burkina Faso	Senegal	Egypt	Algeria	Morocco	Tunisia
Wastewater treated [1000 m^3/day]	< 5 (2011)	< 5 (2011)	38 (2011)	Not reported	317 (2006)	485 (i.e. 25% of the wastewater) (2011)	658 (2010)
Ratio: treated wastewater/ inhabitant (L/ person/d)	<0.2	<0.3	3.2	-	9.6	14.3	63.2

[1] The treatment efficiency might be unsatisfactory

of water treatments units. It was mainly addressed to wastewater treatment plant (WWTP) managers and other specialists working on the ground, within the sanitation sector. Q3 aimed at gathering information on the reuse of the treated wastewater. It was addressed to users of treated or untreated wastewater.

The identification of key stakeholders per country was done by the national partners. In many cases, the operators/technicians in charge of the O&M of WWTPs were not fully aware of the specificities of the technologies, leading to incomplete data collection. On the other hand, given the high number of TPs in some countries, only selected WWTPs were investigated in detail.

Results and Discussion

Wastewater treatment plants

Amount of wastewater

Total amounts of wastewater treated in each target country are presented in Table 2. As a general observation, a sewer system provides the core of the wastewater inflow to WWTPs. Additional septage transport by trucks is also present, especially in some SSA cases. In the 3 SSA countries, less than 5 L/d/person of wastewater are treated. The situation is significantly different in North Africa where ratio reaches 63 L/d/person in Tunisia. The sewerage network is also quite well developed, with e.g. over 80% of households connected to sewer in Algeria and Tunisia. On the other hand, given the relatively low per capita water consumption, all plant types deal with high organics and nutrient concentrations, compared to WWTPs in developed countries. The specific flow rates of wastewater being treated in one WWTP are also highly variable over the continent. While there are below 200 m^3/h per WWTP in SSA (except for one WWTP in Dakar having 1,200 m^3/h of hydraulic flow rate), many WWTPs have some 3,000 to 5,000 m^3/h of hydraulic flow rate in North Africa.

Treatment processes in use

Table 3 presents an overview of the most used technologies. Activated sludge (AS) and stabilization ponds (either aerated or not) are the most used technologies in Africa (Figures 1-4). In all target countries, both technologies represented 68-100% of all implemented units still in operation. In Ghana, AS systems are applied mostly by private entities (industry, hotels) while ponds are preferred by public entities. But, as shown in Figure 5, a wide range of treatment processes are also being operated. Trickling filters were popular some years ago while ponds have now the preference. Many WWTPs are also in disrepair (Figure 6). In Burkina Faso, only ponds are used. However, the remaining five countries show a wider application range at large scale of AS or ponds (Figures 2,4). Combinations of treatment systems for polishing and tertiary treatment rarely exist. It is to be noted that many of the described plants are aged.

Table 3: Overview of the WWTPs in operation.

Country	Total number	1st most used technology	2nd most used technology	3rd most used technology	Feed flow rate (m^3/h)
Burkina Faso	2	100% of ponds	N/A	N/A	96 (for the largest)
Ghana	19[1] (4 ponds under construction)	42% of ponds	26% of AS or aerated tank	16% of anaerobic digesters, etc.	1 - 25
Senegal	9	56% of ponds	44% of AS	N/A	28 - 1,200
Algeria	123 (96 under construction[2])	55% of ponds	45% of AS	N/A	8 - 2,750
Egypt	> 99	Between 65 and 85% of AS	About 10% of ponds	Others	-
Morocco	> 100	>77% of ponds	5% of AS	Trickling filters, etc.	12 – 4,914
Tunisia	109	82% of AS	13% of ponds	Trickling filters and wetlands	4 - 3,250

[1] 6 WWTPs that are only partially functioning (likely with low performance) and are not considered in the total number.
[2] Among plants under construction, 60 are AS and 36 are ponds.

Anaerobic digestion for wastewater and/or sludge treatment allows biogas production and electricity generation. But this is very rarely found although the potential might be high. A lack of understanding of the requirements in AS plants for biogas production might be a reason. AS plants with energy generation have been reported from North Africa (Figure 2) and Senegal while 3 cases of anaerobic digestion of liquid waste exist in Ghana. However, willingness to produce biogas is low in countries with significant energy resources such as Algeria.

Figure 1. A WWTP (activated sludge) being operated in Accra, Ghana [From left to right; Stabilization tank, Aerated reactor, Settling tank and treated water tank, reused for lawns irrigation. Real flow rates: about 25 m^3/h].

1.

Figure 2. The Choutrana wastewater treatment complex (activated sludge + anaerobic digestion of excess sludge) in Tunisia. The 2 WWTPs, designed for a total of 1,300,000 population equivalent. Real flow rates: 3,250 m^3/h for the oldest, 1,667 m^3/h for the most recent (Al Ayni, 2012)

Figure 3. A faecal sludge treatment plant (pond system) in Sekondi-Takorady, Ghana. From left to right; Faecal sludge discharge area (from trucks); Series of ponds. Treats about 100 m^3/d of faecal sludge.

Figure 4. The Mahdia WWTP (aerated pond system), in Tunisia. It is designed for 150,000 population equivalent (Real flow rate: 426 m^3/h). Treated water is UV-disinfected before discharge (Al Ayni, 2012).

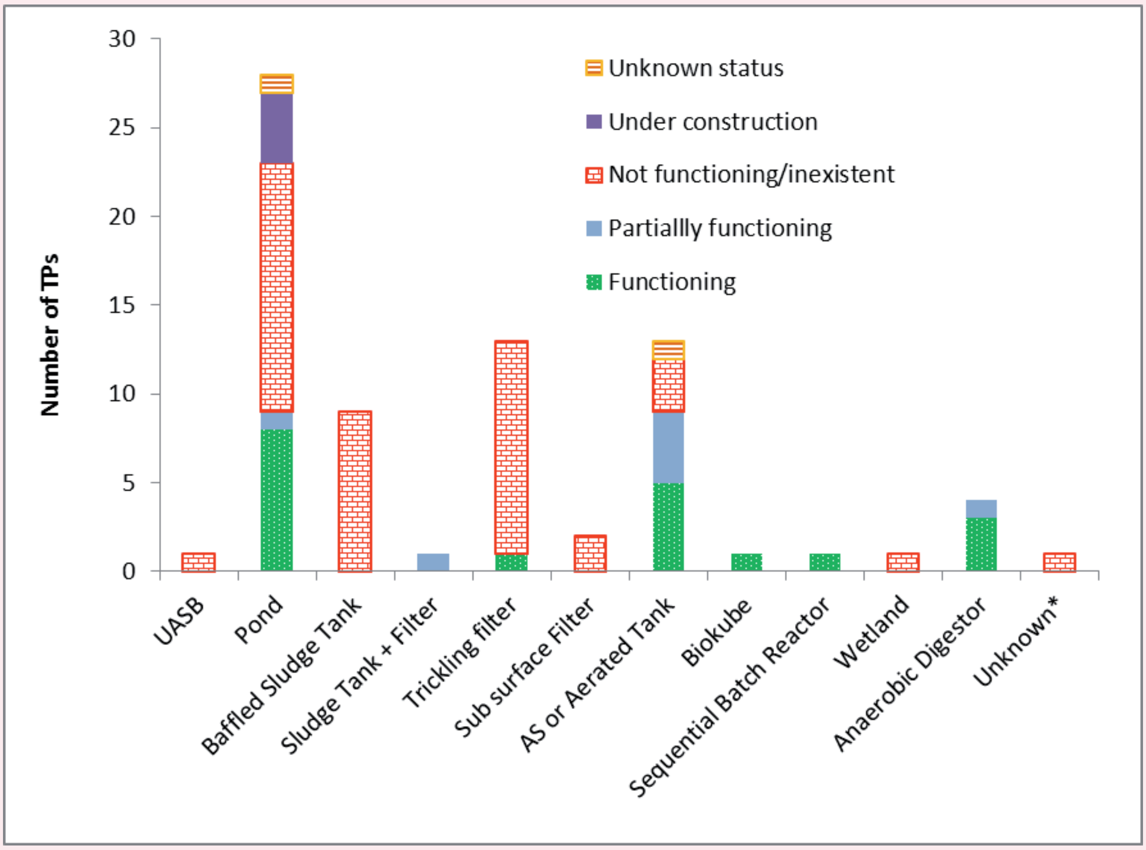

Figure 5: Distribution of technologies in Ghana (UASB: Upflow anaerobic sludge blanket, Adapted from Murray and Drechsel, 2011).

Figure 6. A WWTP in disrepair in Accra, Ghana. From left to right; pump, aerated reactors, settling tank, weedy drying bed.

Challenges in the operation of treatment plants

The survey showed that several challenges influence the operation of WWTPs (Table 4). Among technical challenges, insufficient capacity to cope with increasing wastewater load (e.g. because of population increase) is a commonly reported problem. In case of strong deviation between wastewater collection and treatment capacity, a substantial part of sewage is released untreated (e.g. for Camberene WWTP, Senegal). Another key challenge WWTPs in Africa have to cope with is the pollution load variation, caused by uncontrolled discharges into the sewage network (e.g. from industrial discharge), a result of non-enforced regulations. Power cuts are a severe issue where processes with energy demand take place. Poor O&M, leading to inappropriate sludge disposal and odour generation and lack of re-investments are also reported.

Financial problem arises in all countries, negatively affecting the O&M, the construction (e.g. unfinished WWTPs in Morocco) or the upgrading of WWTPs. High energy costs are also cited as key constraint in all countries. In terms of management, differences can be observed, depending on the nature (public, private) of the operators. In the public sector, many WWTPs suffer from heavy administrative procedure for O&M and lack of short-term maintenance planning. Workers in charge of treatment plants often lack the full capacity to maintain them and are not motivated/encouraged to maintain treatment plants.

As a result, WWTPs often deliver insufficient effluent quality, causing complaints from stakeholders. Release of insufficiently treated wastewater into the environment is also observed where treatment plants are dysfunctional or temporarily disconnected (common in Ghana).

Quality requirement applied to treated effluents

Table 5 presents selected quality requirements for WWTPs in Africa. These values are compared with their European counterpart found in the Urban Wastewater Treatment Directive of the European Union. This table reveals that regulations on treatment standards and effluent requirements differ over the case study countries. In the 3 SSA countries, the standards to be achieved by treated effluents mostly rely on the WHO guidelines. But it is essential to emphasize the fact that regulation is not always enforced on a regular basis. Upstream enforcement of regulation (e.g. for the industries connected to the sewerage) is almost inexistent in all 3

Table 5: Selected parameters requirements for WWTP effluents in Africa and the European Union

Location	COD (mg/l)	BOD (mg/l)	Total N (mg/l)	Total P (mg/l)	Hygiene CFU/100ml
EU[1]	125	25	-	-	-
EU[2]	125	25	15 [3] or 10 [4]	2 [3] or 1 [4]	-
Burkina Faso	150	50	-	-	FC: 1,000
Ghana	250-400	50	-	-	TC: 400
Senegal	100-200	40-80	30	10	FC: 2,000
Algeria	90	30	51.5	10	FC: 2,000
Egypt	40-80	20-40	-	-	EC: 100
Morocco	250	120	-	-	-
Tunisia	90	30	1-30	0.05-0.1	FC: 2,000

[1] For non-sensitive areas and all plant sizes.

[2] For sensitive areas and plant size >10,000 population equivalent (PE).

[3] For plant size < 100,000 PE.

[4] For plant size >100,000 PE.

Table 4. Summary of the reported challenges (top 4 challenges per country are numbered).

	Burkina Faso	Ghana	Senegal	Algeria	Egypt	Morocco	Tunisia
Technical	3. No control over industrial disposals 4. Power cuts • Limited removal of nitrate or iron 2. Lack of compliance with the regulations	1. Pump failure 4. Power cuts • Overloading	3. No control over industrial disposals 4. Power cuts • Limited removal of nitrate or iron 2. Lack of compliance with the regulations	1. Power cuts 2. Industrial wastewater inputs (e.g. presence of oil) 3. Sludge discharge	• High loading rates • Lack of spare parts • Limited infrastructure for biogas reuse	4. Pump failure • Power cuts • Lack of control over wastewater feed • Foaming in activated sludge WWTPs • Poor management of sludge produced	2. Sludge elimination
Social	• Solid waste disposed in the collection network • Robbery • Vandalism	• Waste thrown in sludge • Complaints about odour and breeding of mosquitoes	1. Pump failure 4. Power cuts • Overloading	• Need of capacity building for sludge management	• Need of capacity building for sludge management • Low wages of workers causing lack of motivation	3. Limited qualified personnel Inadequate standards and regulations	-
Economic	1. High O&M costs	1. Lack of funds for O&M or rehabilitation 3. High O&M costs	1. Non-sustainable funding sources (charge fees are not sufficient) • Lack of funds for O&M (e.g. fuel for generator)	4. Outdated equipment	• High O&M costs • High cost of WWTP	1. Inadequate infrastructure 2. High O&M costs of treatment systems and sewerage networks	1. High energy consumption
Environmental	.	• Odour affecting locals in the vicinity	4. Deterioration of living conditions of populations • Groundwater pollution • Ecosystem disturbance	-	• Water reuse should be optimized at least for forest trees	• Air pollution (e.g. release of odours)	-

Table 6: Summary of main challenges (top 3 challenges per country are numbered) in reuse of water (user and WWTP manager perspective)

	Burkina Faso	Ghana[a]	Senegal	Algeria	Egypt	Morocco	Tunisia
Supply	1. Unsuitable Water quality 3. Odour in the water	1. Shortages of water supply (seasonal and intermittent) 2. Odour and filth in the water 3. Poor water quality	1. Inadequate infrastructure (e.g. for transport of treated sewerage to re-users)	1. Unsuitable quality of treated water • High water availability	-	1. Inadequate infrastructure • Bad water quality (salinity, pathogens)	1. Poor water quality due to high levels of pathogens and salinity
Social	2. Lack of supervision of treated wastewater users	-	2. Lack of potential users for treated water (given the location of the WWTP)	2. Lack of synergy between ministry of agriculture and ministry of water resources 3. Stringent regulation	• Lack of political will • Strict standards and regulations	2. Limited public/ farmers acceptance and awareness • Institutional set-up not allowing proper coordination • Lack of political will • Strict standards and regulations	-
Financial	-	-	-	• Low willingness to pay for treated water (prices must be subsidized)	• High O&M costs of networksP	3. Low willingness to pay for treated water High O&M costs of networks	2. No willingness to pay for the treated water
Long-term Impacts	• Reduction in soil fertility	-	-	-	• Deterioration of soil structure (due to salinity)	• Negative impacts of nitrogen excess • Deterioration of soil structure (due to salinity)	-

[a] In many areas in Ghana, farmers use mostly untreated wastewater, which is diluted to different degrees.

countries while quality of final WWTP effluent remains unsatisfactory and rarely controlled in many cases.

In North Africa, strict emission thresholds can be found, especially regarding COD (all countries, except Morocco) and phosphorus (Tunisia). For these parameters and countries, the national standards are even stricter than for the European Union (UWWTD, 1991). Such situation should result in the need of implementing highly effective WWTPs in order to match the regulation, which therefore would reveal expensive to operate. On the other hand, it is important to highlight that limitations of nutrient levels in treated effluents to be reused in agriculture, can be contra-productive. In some countries, some specific standards have been adopted for treated water to be reused in agriculture (e.g. Tunisia).

For all countries but Morocco, thresholds for hygienic parameter for treated domestic effluents are fixed, whether expressed in terms of faecal coliforms (FC), total coliforms (TC) or E. Coli (EC). However, such limitation could only be justified when the treated water is reused or discharged to sensitive receiving areas (e.g. with nearby DW resources). Likewise, this requirement only implies further treatment costs but does not support environmental conservation.

Challenges related to treated wastewater reuse

The situation of water reuse in Africa is highly variable. In some locations, water reuse is been practiced without much legal control. This is the case of Accra (Ghana) where water from drains is reused for growing a wide range of vegetables, even when it undergoes no proper treatment. In Burkina Faso, the government has agreed with the reuse of wastewater and has therefore developed areas for market gardening using this resource under some restrictions (only for selected vegetables). But in Senegal, water reuse is not always practiced even if a potential exist for that (current uses include gardening or livestock watering) for reasons including unsuitable location of the WWTP which causes the treated water not to be accessible to potential users.

The most important challenges with reuse acceptability in agriculture are observed in the case study countries of North Africa. While, on the one hand, Morocco significantly limits this practice for agriculture, Egypt on the other hand encourages it for selected farming activities. In practice, 45 % of the treated water in Morocco (25% of the wastewater undergoes any form of treatment) is reused, mainly for lawn irrigation, groundwater recharge and by industries. In Tunisia, it is used for golf courses and other green spaces' irrigation. In Algeria, the main uses include town road cleaning and for cooling fire engines. In all these 3 countries, the use in agriculture is limited. In Egypt, the permitted use of treated water depends on its quality.

Table 6 presents a summary of the challenges that water reuse faces in the target countries. Several reasons can justify the limited success of water reuse in agriculture for the concerned areas. Firstly, it shall be observed that water reuse is promoted in areas where access to water is scarce and no other water source (surface or groundwater) available at low cost (e.g. in SSA and Egypt). When there is competition with other water sources, treated water reuse is not successful. Under these circumstances, willingness to pay the water is also low, and it contributes to generating unfavourable conditions for water reuse. Low tariffs on fresh water (in Algeria, Morocco and Tunisia) also limit the possibility to sell treated water for irrigation and to generate significant income for WWTP operation. In general, cost recovery from reuse (if existent) is too low to cover even the operating costs of the added irrigation components, leading to dependency on foreign aid and governmental support. Exceptions can be treatment systems generating energy (Evans et al., 2012). Other socio-economic or political factors such as a lack of awareness, on both governance and user (e.g. farmers) sides, also impact willingness to pay.

Indeed, water reuse often suffers from bad perception from farmers (detrimental effect on soils and plants) and consumers.

Insufficient infrastructure and unsuitable treated water quality (high pathogen and salinity levels) are other factors that inhibit reuse. Specifically, insufficient pathogen removal in reuse water poses risks to health, especially if alternative risk reduction options are not in place, as advocated e.g. by WHO (2006).

Conclusion

This paper aimed at analysing the current experiences of 7 African countries in terms of wastewater management. It informed on some challenges and drivers for the current situation and confirmed the gap between North Africa and Sub-Saharan African countries. The study revealed that activated sludge and ponds systems are currently the top 2 technologies applied for wastewater treatment and overall represent over 70% of treatment units in the Region. But many WWTPs are subject to transition, especially in the fast growing urban centres of Africa. In addition, in most countries, not all wastewater is collected (e.g. through sewer systems) and not all collected wastewater is treated. This situation gives room for further diversification on existing systems as well as creating opportunities for new developments. Currently, in SSA, WWTPs are mostly expected to treat low flow rates effluents (< 200 m^3/h), but large systems with up to 5,000 m^3/h of flow rate, are also encountered in North Africa. The national standards in many African countries will benefit revisions to include achievable targets for essential parameters. Indeed, most entities in Africa cannot afford the high energy prices and operation costs of the systems, which require a trained and qualified staff as well, needed to be implemented in order to meet the current standards.

It is established that reuse of treated water, e.g. in agriculture, can help in reducing stress on valuable fresh water resources in two ways; avoiding their pollution and reducing their consumption, especially in urban and peri-urban areas. The lack of adequate infrastructure for water collection or treatment also causes the bulk of domestic and/or industrial wastewater to be discharged without any treatment, with damages health and environment. In principle, wastewater reuse provides a mean for income generation. However, in some countries, low quality of treated wastewater or restrictive legislation does not allow WWTPs and users to benefit from the reuse. Anyway, the complexity of the problem requires adapted approaches considering technical, organizational and governance aspects, like promoted by WHO (2006).

Acknowledgements

The work was carried out within the WATERBIOTECH coordination and support action („Biotechnology for Africa's sustainable water supply", Contract No. 265972-KBBE; duration: 1.08.2011 – 31.01.2013) funded within the EU 7th Framework Programme. The WATERBIOTECH team is grateful for the support of all stakeholders. The authors are also highly grateful to the partners, especially the African partners, who have provided the data reported in this paper.

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What do we require from water biotechnologies in Africa?

This paper shows requirements and obstacles towards sustainable biological wastewater treatment in Algeria, Bourkina Faso, Egypt, Ghana, Morocco, Senegal and Tunesia.

Authors: Norbert Weissenbacher, Josiane Nikiema, Marianna Garfi, Alberto Figoli

Abstract

When discussing water and sanitation issues, technology is often seen as the key element by many stakeholders. Within a multinational project, the opportunity was taken to analyse the experiences with the existing water infrastructure to look behind this assumption and – if not working satisfactory – to identify the key requirements that obviously have not been met. Following this, it should be possible to prepare a set of requirements to learn from this. A three stage questionnaire for different stakeholder level (authorities, operators and end users) has been launched in Algeria, Burkina Faso, Egypt, Ghana, Morocco, Senegal and Tunisia. Some main obstacles towards sustainable biological wastewater treatment could then be identified. The reader expecting specific technical suggestions might be disappointed but the key messages that are relevant for all the different conditions of the four North African and the three Sub Saharan countries are presented. The given requirements tackle issues that are unfortunately not only of technical nature and are (almost) all linked to each other.

Introduction

The survey conducted within the WATERBIOTECH project (www.waterbiotech.eu) showed that numerous technical and non-technical aspects can influence the success of system operation. The results also showed that there is a rather small number of different water biotechnologies applied in the partner countries involved in the project. Whereas the water supply side mainly relies only on physic-chemical methods, wastewater treatment seems to be dominated by the biological treatment methods of activated sludge systems (AS) and pond systems (PS). Despite some exceptions, the type of technology present

Key facts:

- Operation costs shall be as low as possible and maintenance requirements shall be in line with local capacities
- Technologies shall be insensitive to normal industrial inflows and load variations
- Technologies have to comply to effluent standards given

…but at the same time it has to be ensured that:

- Legal standards reflect a reasonable balance between risks minimization and feasibility
- Legal standards shall consider envisaged water reuse
- Legal standards have to be enforced in practice
- O&M requirements are met by appropriate organisation at any time
- Industrial impact is regulated and limited by appropriate means

The authors therefore conclude that in Africa a practice- and system-based approach is required for introduction of water biotechnologies (rather than following paper-based strategies prepared for other developed countries). Adapted legal frameworks with less stringent requirements could make it easier to reach scale and strengthen local economy at the same time.

could not directly be blamed for the failures – it is more the combination of the type of selected technology with the non-technical conditions present that do not work out.
Given many problems with external infrastructure (energy, materials and supplies), practice reflects that extensive/simple systems seem to have a higher probability of long term operation than intensive (technical) systems. But even for pond systems, the development of the associated catchment leads to significant problems. The background of the investigated regions shows different infrastructure conditions with significantly lower sanitation and wastewater coverage in the Sub-Saharan countries. On the other hand water reuse is a more pressing issue in North African countries given that wastewater is often the most reliable water source in dry climates. More details on the survey results and the methodology applied in the survey are described in Nikiema et al. (2013).

The objective of this paper is to summarize the most important requirements for local adaptation that have been extracted from the surveys and to discuss some issues that are linked to them.

Technical requirements

Many of the technical requirements given below should be common knowledge for planning engineers and also necessary aside the target regions of the project. Anyway, the summarized points below are directly tackled by the challenges reported in the survey and therefore worth to be repeated. Besides the bullet points of the requirements itself, some critical discussion points have been added to show the relevance of non-technical aspects that impact technology implementation and complicate engineer's life.

Treatment performance

<u>Legal compliance and impacts on health and environment</u>
The treatment capacity has to comply with regulations and has to ensure that no harm is posed to humans and the receiving environment (aquatic systems and water resources):

- Legal compliance specific to each country and area.
- Low toxicity of remaining pollutants on fish; e.g. low levels of ammonia.
- Low levels of N and P to avoid eutrophication.

Numerous problems arise with the issue of legal compliance. A legal framework should cover the risk management of wastewater treatment, disposal and reuse for the conditions where it is applied. Under this assumption, the durable compliance of a system keeps health risks and environmental risks at an exactable level. As basis, the thresholds given for the effluent has to be achievable by a system. In many cases, developing countries copy requirements from others (developed countries) or even worse: They set more stringent thresholds. It is not to be forgotten that, in developed countries, the current legal framework reflects the status of a (costly) system development and upgrade over decades. This development followed a stepwise improvement - from mechanical treatment, carbon removal up to tertiary treatment (where necessary).

For example, economically and technically feasible technologies cannot meet the stringent P requirements given in Tunisia (P levels below 0.1 mg/L!). Also, since many projects are funded externally and national and international tender procedures apply, intensive (technical) systems get favoured over extensive ones as a consequence. The dependence on foreign technology import is prolonged when the offered solutions have to comply with strict effluent requirements.

As second aspect, compliance requires the knowledge on system performance and its control. As first part of this, the operator has to be able to measure something and, as a consequence, to react according to the results. This implies costs on analytical materials and equipment but also sufficiently trained personnel. Both efforts are dependent on the number and nature of parameters to be covered. Secondly, regulators have to be aware of the operation results and have to verify them externally. Again, time and resources are needed. Practice shows that capacities on both sides do not meet these requirements in many cases.

<u>Reuse</u>
In case of water reuse, the effluent quality has to prevent adverse impacts on humans, the receiving environment and agricultural production (but to keep beneficial nutrients for plant uptake):

- No further contamination of groundwater, e.g. with pathogens.
- Low salinity.
- Possibly high nutrient (N and P) levels.
- Low pathogen contamination.
- Low suspended solids (to avoid sedimentation in the irrigation devices).

Legal compliance issues apply in the same way for reuse purposes as stated earlier. Since reuse of treated water may be an input to the food chain, this is even more important. But frameworks have to consider the nature of the reuse envisaged. This means that nutrients shall not be removed since they are needed. Hence, treatment costs can be reduced and the market position of the reuse water strengthened. In some North African countries, water subsidies for irrigation water (from public water supply) counteract water reuse from wastewater treatment by reducing its market value. Considering the important aspect of hygienic risks, wastewater treatment is only one step in the reuse chain. Selection of crops, transport, irrigation system and other aspects contribute to a successful reuse system (see WHO guidelines; WHO, 2006). Studies revealed that even the handling of the crops during transport and market are more relevant for hygienic contamination than the treatment of the used wastewater itself (Ensink, 2010). Discussing safety issues and having in mind that at many places of the investigated regions informal use of (untreated) wastewater is in place, practicable solutions for reuse are urgently needed. Figure 1 shows the effluent of a pond system for agricultural reuse. Here, farmers reduced the use since adverse impacts on crops have been observed (and not because some parameter thresholds where not met). The plant suffers from adverse industrial impacts (see also next chapter and Nikiema et al., 2013).

Plant size

Catchment development

The system size has to be designed to cope with the amount of current connection load including a certain (estimated) future increase.

- Selection of technology according to level of centralisation needed.
- System must be able to cope with anticipated changes of settlement structure (urbanization).
- Size must take into account the estimated future increase of inhabitants.

Currently, many systems suffer from overload conditions with the consequence that wastewater can only be partly treated. One reason is that the treatment capacities have not been planned accordingly or been increased in parallel to the collection systems or that a significant input comes from informal connections. As population is rapidly increasing in many peri-urban and urban areas in Africa, the systems have to cope with increased loadings as well with changed wastewater quality (impact of industry and businesses, see below). A transition of infrastructure with increasing level of centralisation has to be considered. Decentralized systems might be appropriate for a certain time period, and then sewer connection might be necessary to cover increased settlement density. Hence, the suitability of technologies might change with such considerations.

Local capacities

The management and O&M requirements related to the plant size shall be in line with local capacities.

- Complexity has to be appropriate for expertise available.
- Capacity building to increase and regularly adapt human resources shall be possible.

Generally, small systems with responsibilities of the end-user for operation require low complexity. For larger scale and technical systems, the operator is a key element. Often the resources for personnel are limited or redirected from their designation to finance other community issues. This leads to failure in many cases. Also the lack of internal and external monitoring contributes to a low awareness on capacity building within operating institutions (see also section on O&M).

Figure 1: Effluent for reuse: wastewater treatment plant (WWTP) in Ouagadougou, Burkina Faso.

Figure 2: Decentralized system for rural community: Constructed wetland system in Tunisia.

Land and space requirements

The applied technology shall ensure the required performance at a minimal aerial footprint in cases where land availability is low (and land is expensive). Further, the technology selected shall consider other topographical limitations (e.g. steep hills, mountainous regions) and shall be appropriate for the local soil properties. If the location enables the application of sanitation by-products (e.g. compost), this should be considered in the technology selection. Extensive systems like ponds and wetlands generally require relatively large space for implementation whereas the high temperatures in African regions lead to reduction of the required area due to the higher microbial activity compared to temperate climates. Technical systems concentrate the biological turnover on smaller footprint but that leads automatically to higher complexity of the system. Figure 3 shows the impressive surface area of a pond system.

Treatment versatility

The biological treatment system has to be adaptable to cope with pollution characteristics (composition, toxic content) originating from industrial discharges.

- The WWTP shall be able to treat wastewater generated by local industries to a certain extend (depending on the type of industries).
- Technology shall allow flexible control of the process, in case of a variation in the industrial waste composition.

As already mentioned, settlement development and economic growth is often way faster than the infrastructure development in the investigated areas leading to significant impact on public treatment facilities. System failures are reported from simple overload condition due to (often informal) industrial input but also from direct system inhibition from toxic industrial wastes. Biological treatment systems can only cope with industrial inputs to a certain extend. Buffer volumes may help but, in case of strong toxic impacts, the microorganisms allowing pollution removal in the treating system are simply killed and the facility loses its whole capacity. In that case, a strict diversion of the toxic wastewater is the only way to go. Industries achieve the capacity to operate special treatment for their wastes easier than communities where technical capacities are normally limited (it is also easer to treat small amounts of strong toxic wastewater than large amounts of diluted toxic effluents). Even 'high tech' systems like MBR are not insensitive to industrial impacts. The potentially higher sludge age allows the adaptation of the biomass to hardly biodegradable matter to some extent but not to toxic constituents. Figure 4 shows a plant that suffers from seasonal impact of the olive oil production wastewaters – a problem that is encountered in many Mediterranean countries.

The second requirement for flexible control to cope with changing conditions will remain a wish - especially in the target regions. Even in Europe this poses a problem to AS plants which are connected to industries. Inflow monitoring connected to forecast for the indolent biological community are a matter of ongoing research and far from practical implementation.

Further, diurnal variations have to be considered:

- WWTPs must be insensitive to usual daily load variations.
- WWTPs must be insensitive to normal seasonal load variations.

Proper system design normally accounts for inflow variations by the introduction of safety factors (e.g. the German DWA A 131 guidelines for activated sludge

Figure 3: Large space requirement for pond systems: Ouagadougou WWTP (Burkina Faso); Treating 96 m^3/h of domestic and industrial wastewater.

Figure 4: Domestic MBR plant with impact from olive oil production wastewater (inhibition due to phenolic compounds; Israel).

systems). However, critical operation conditions (and load peaks) have to be defined as input for system design. Influent equalization using buffer volumes helps in most cases to achieve a more or less constant effluent quality. This is especially important for small systems where the diurnal variations are pronounced.
Since domestic water use is relatively low in the concerned regions, the pollutant concentrations are relatively high which also has to be considered in the system selection and design.

Climate impact

Where the effluent shall be reused, evaporation shall not significantly impact the effluent discharge volume. Temperatures have to be a variable input parameter for system design to ensure optimal lay out for the local climate conditions. In general, biological systems are positively impacted by the higher temperatures in dry and tropical climates – an advantage that can be utilised in reducing the plant dimensions accordingly (to reduce costs).

Excess sludge

The wastewater treatment selection has to consider the amount of excess sludge produced and the connected de-sludging frequency that is needed. It has to include a sufficiently dimensioned sludge treatment and disposal mechanism that prevents any severe nuisance or adverse impact on the surrounding environment. Sludge treatment shall provide a sufficient quality for further use, with adequate chemical composition and low pathogen levels. In case no further use of bio solids is foreseen, the volume of produced excess sludge shall be kept as low as possible.

Resource orientation

The quality of available sanitation by products (compost, struvite etc.), if available, must allow safe handling and prevent adverse effects on health and environment from agricultural application.

- Good chemical and bacteriological properties of composts and other by-products.

Not only the generation of water for reuse but also the recovery of nutrients and organics opens the gate to the invisible benefits of the sanitation chain. The latter term ‘chain’ is the key to resource orientation since the production and application of e.g. composts and struvite needs the establishment of a service chain from collection over processing to marketing. This approach is subject of numerous projects especially in sub-Saharan Africa and has been already implemented at larger scale (Figure 5). Here economical feasibility strongly depends on the market generation. Besides the dry sanitation systems that are known as resource oriented, also the recovery of nutrients and the use of bio solids from wet systems is resource orientation. Wet and dry systems can be also combined to achieve resource efficiency (Masi, 2009).

Operation and maintenance

As central issue of wastewater treatment and sanitation, the survey revealed many challenges that are related to the O&M issues with the frequent statement that somebody is (officially) in charge but does not (or cannot or does not want to) do her or his job.

- Under limited local capacities extensive treatment systems with low O&M efforts shall be used.
- In case of complex systems under limited capacities, automation in combination with contractor’s support shall provide proper operation.
- Consideration of locally available supplies shall be as high as possible.

In most cases reported, the lack of O&M is somehow related to the financial capacities. This starts with the lack of money for costly equipment replacements (mainly pumps), to the low motivation of personnel due to low remuneration and finally to the shutdown of important plant parts or whole plants because of their electricity consumption. Hence, in any case (also for large AS systems) it is demanded that the operation and maintenance efforts shall be as low as possible. The suggested use of automated control for operation is a future option for domestic systems and limited to industrial facilities at the time being. It remains to

Figure 5: Urine storage for agricultural application in Ouagadougou.

stress again that from experience the extensive systems can be trusted to achieve at least a certain degree of performance at limited O&M efforts (but not without O&M). On project level, O&M has to be incorporated as a long term component including external monitoring and backstopping for technical systems.

Energy demand

Energy demand is an issue repeatedly stated in the survey and in most cases related to costs or the impacts of an unstable public power supply on the system performance. Where pumping cannot be avoided, the selection of the technology has a clear impact on power consumption.

- Treatment process and control shall be as independent from powers supply as possible.
- If control systems require permanent power, uninterruptable (self sufficient) supply has to be provided.
- For systems with permanent power demand for processing the wastewater, energy production shall be available to cover as much as possible of the demand.

Low power demand allows the introduction of e.g. solar powered operation, an option for smaller systems and low hydraulic volumes to be pumped. The electricity generation from anaerobic treatment is sparsely introduced despite the huge potential for large systems. The high temperature conditions support the efficient operation of digesters in Africa – even for smaller scale units than applied in Europe. On the other hand anaerobic digestion increases the plant complexity and also safety issues have to be considered.

Recommendations and conclusion

The insight in the experiences of the investigated countries has shown that there is the need to simplify some aspects for the scale up of wastewater treatment biotechnologies. The legal framework plays a fundamental role to enable the potential of the full range of water biotechnologies that is often hindered by over regulation. This would allow stepwise infrastructure development at reduced costs and foster local businesses in this sector. The results showed that the industrial wastewater burden cannot be laid on technologies alone, this also needs an enforced regulatory framework.

The summarized requirements have to be considered during a sound system selection and design. The planning process itself therefore remains crucial. It has to consider costs and benefits, future developments and long term operation and maintenance. Therefore, knowledge on the various options of biological wastewater treatment has to be transported in a practicable form to the local engineer. Simplified tools for practical application are needed where the pool of technologies is the backbone.

The results also showed that water reuse and resource orientation are of increasing importance. The question is if these needs will enable sustainable wastewater treatment in future. As a question of economics, only a reasonable value of the marketable product will provide the necessary resources to do it as long as sufficient public subsidies are missing.

Acknowledgements

Thanks go to all involved partners from the WATERBIOTECH project.

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Aquifer Recharge by Treated Wastewaters: Korba case study (Tunisia)

This paper describes the evolution of groundwater quality after recharge with treated wastewaters.

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Abstract

The recharge of Korba aquifer (Tunisia) by treated wastewater (TWW) via infiltration basin is monitored since 2008 for the changes occurring in groundwater quality after three years of recharge through three significant parameters controlled throughout the studied area: salinity, nitrates concentrations and total coliforms. In this study period, the project shows an improvement of the salinity groundwater levels but no net change in the distribution of nitrate and bacteria else than displacement of the polluted area.

Introduction

Agriculture is considered as the biggest consumer of water in Tunisia as it uses up to 80% of the available freshwater. Groundwater, which represents an important source of available water in Tunisia, is overexploited at a rate that exceeds 103% of it's natural recharge. The use of different kinds of fertilizers has additionally damaged qualitatively and quantitatively the groundwater (El Ayni et al., 2012a; Kouzana et al., 2009) causing a decrease in piezometric levels, seawater intrusion (El Ayni et al., 2012b) and rising levels of contaminants like nitrates and other various salts.

Simultaneously, this high salinity groundwater is drilled to be used for irrigation therefore increasing agricultural land salinity and reducing land productivity. It sometimes turns up to complete loss of usefulness of the irrigated land (Gaaloul et al., 2003). On the other hand, the use of salty waters for animal drinking purposes may be hazardous for animals and may render milk or meat unfit for consumption. These waters need to be studied for their quality and suitability before being used in agriculture (El Ayni et al., 2011).

Key data and facts:

- High contamination in groundwater prior to recharge: salinity up to 8.5 g/L, nitrates (81-332 mg/L) and bacteria (30 - 11,000 per 100mL).
- Depletion of the aquifer due to the overexploitation of the aquifer for irrigation purposes prior to the recharge operation that would solve part of this problem.
- The salinity of the treated wastewater (TWW) varies from 1.8 to 5.4 g/L with seasonal fluctuations of bacterial and nitrate contamination.
- Infiltration basins for the TWW recharge are near the treatment plant.
- Infiltration capacity: 0.5 m/day.
- 3 basins with a total surface of 4500 m^2.
- The infiltration basins serve three objectives: retention of the suspended solids, oxidation of the dissolved organic matter and the oxidable nitrogen, removal of pathogenic micro-organisms.
- The main objectives are to reduce TWW pollution, to allow TWW reuse and to enhance the aquifer level and quality.
- Advantages and effectiveness of the project to cure high salinity. Nevertheless, contamination by nitrate and bacteria remains a major problem of the aquifer.

The situation is worsened when the phenomenon of bad groundwater quality is added to water scarcity as it is the case in many regions of the world including the Mediterranean countries. Tunisia is located in an arid/semi-arid region of the southern shore of the Mediterranean Sea. This is why this country searches for alternative water resources in order to fulfil its water needs, especially for agricultural utilization. The reuse of treated wastewater (TWW) has been applied in the last few decades in Tunisia to direct irrigation of authorized crops like greenspaces and golf courses. The interest is now focused on the reuse of TWW to recharge the aquifers, meanwhile solving several health, environmental, agricultural and economical issue. Many projects have been conducted elsewhere for the recharge of aquifers by TWW and have shown positive impacts on the aquifer e.g. in 1985 at El Paso (Texas, USA) where wastewater was treated by tertiary treatment serving dual purposes of the reuse of the wastewater and the restoration of groundwater (Sheng, 2005). In Dan region (Israel) tertiary treated wastewater was used for the recharge of an aquifer during a 300 days experiment, the resulting water met irrigation standards with non restrictive use as no bacteriological contamination was found in the aquifer (Idelovitch, 1978). On the other side, irrigation with waters from wells refilled by TWW can decrease fertilization use and costs due to the nutrients that it contains (Haruvy et al., 1999). Thus the reuse of TWW by recharging aquifer would help not only to struggle against water scarcity but also against marine intrusion in coastal areas. It is also a mean for groundwater remediation when using infiltration basin systems for recharging qualitatively deteriorated aquifer.
The aim of the present paper is to investigate the impact of recharging a deteriorate aquifer by tertiary treated wastewater in a semi-arid climate in Tunisia (Korba) especially by monitoring the groundwater salinity remediation. The results would allow us to evaluate the effect of TWW on this aquifer in order to suggest adequate solution to water scarcity and destruction of the regional aquifer as well as solving the problem of TWW safe elimination.

quality. This is especially important for small systems where the diurnal variations are pronounced.
Since domestic water use is relatively low in the concerned regions, the pollutant concentrations are relatively high which also has to be considered in the system selection and design.

The study area: Korba aquifer

The studied area is located in Korba, a coastal region in the North-eastern Tunisia (Africa). Geologically, the region (Pliocene-quaternary) is mainly composed by sandstones, conglomerates and clay. The dominant economic activity is agriculture with some agro-industries, textile industries and tourism. The principal cultivations are strawberry (270 Hectares), potatoes (1010 Hectares), tomatoes (3000 Hectares), pepper (3000 Hectares) and other vegetables (1200 Hectares).
The population of this region is about 100,000 inhabitants and the region is situated in a zone of moderate rainfall with an annual average between 450 and 500 mm/year. In order to respond to the increased water demand in this region, the aquifer has been highly exploited since the seventies what conducted to a decrease in the piezometric level of the aquifer and generated a degradation of the groundwater quality essentially due to seawater intrusion (Paniconi et al., 2001). The aquifer of the Eastern coast saw a net drawdown of the piezometric level and an alarming increase in salinity that followed the intensification of the local exploitations. This bad situation is related to the digging and the deepening of wells in order to increase the pumped water volumes in addition to the electrification of several wells. The piezometric level of the plio-quaternary aquifer has particularly felt as the piezometric level has seen a 10 m decrease between 1977 and 2004 near the Korba coast (Kerrou et al., 2010; El Ayni et al., 2012b). This situation resulted in marine intrusion, depriving the plio-quaternary aquifer of any contribution of subsoil water. The lowering of the piezometric level of the aquifer in this area is related to the still local increasing exploitation in addition to the low thickness of the saturated zone.

Korba treated wastewater plant

Reclaimed water used to feed the project is provided by the plant close to the infiltration basins which has begun to work in July 2002. This treatment plant is a low-load activated sludge treatment plant combined with finishing lagoons (Figure 1). It is dimensioned for 7500 m^3 of wastewater per day and actually receives about 5000 m^3 per day. It can provide 1500 m^3/day to the recharge site.

The recharge area and infiltration ponds

The aquifer recharge by using infiltration basin consists of water penetration in the soils. This water is generally biologically treated wastewater which goes through the unsaturated zone until it reaches the saturated zone of the aquifer by slow vertical percolation. The unsaturated zone acts indeed as a natural reactive filter that can reduce or remove microbial and organic/inorganic contaminants through biogeochemical processes enhancing mass transfer between soil phases. This process targets the geochemical reactivity and dynamics of the soil in order to improve water quality while maintaining environmental quality and protecting other resources. Thus, the infiltration basins serve as a tertiary treatment of the TWW. The retained site for Korba aquifer recharge project implantation is situated immediately close to the local treated wastewater plant. The initial feasibility study suggested the chosen implantation according to the geological specifications

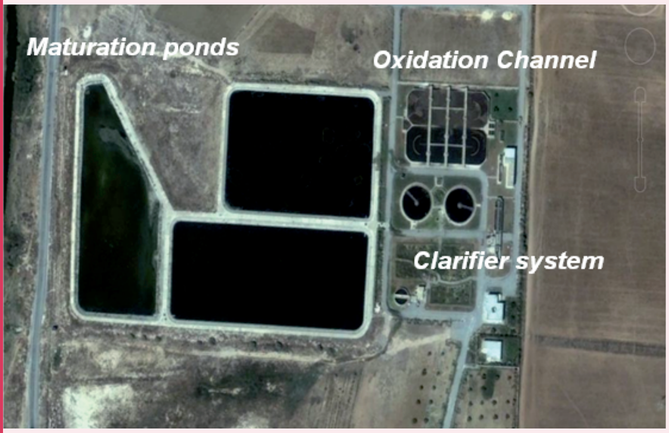

Figure 1. Korba wastewater treatment plant (© 2009 Google)

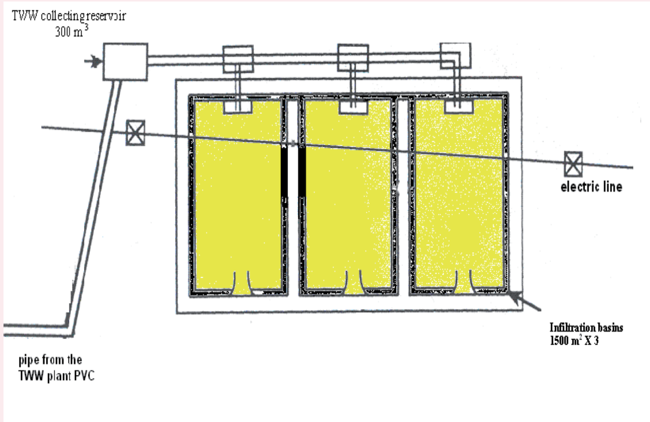

Figure 2. Infiltration ponds for aquifer recharge by TWW

of the site and constructed in order to receive 1500m^3/day of treated wastewater according to the parameters shown below.

The characteristics of the recharge basins are (Figure 2):

1. TWW collecting reservoir: 300 m^3
2. Infiltration capacity 0.5m/day
3. Three infiltration basins 1500 m^2 each (Figure 3).
4. Capacity of the infiltration basins: up to 1500 m^3/day
5. Estimated annual recharge: 0.5 million m^3/year
6. Pipe diameter for basins feeding is 400 mm

The durability of the infiltration process calls for an alternation in the use of the infiltration basins to allow the aeration of the non-saturated zone and also the ponds cleaning in order to restore their infiltration capacity (CRDA, 2008). The advantage for the infiltration ponds technique is the possibility of using the soil as an additional treatment of the wastewater. The disadvantages are the utilization of a large area and the high maintenance costs to avoid clogging that can be a barrier against infiltration process often occurring when treated wastewater is used for aquifer recharge.

Monitoring groundwater quality changes

In order to assess the impact of the recharge of the aquifer by TWW, three significant parameters were analysed from groundwater before and after three years of recharge, as well as in TWW during this period of time. They were salinity, nitrates and total coliform. The analysis were performed in the laboratory of the International Center of Environmental Technologies of Tunis (CITET) that is accredited ISO 17025 since 2001 and followed the ISO (International Organization for Standardization), NF (French standard) and EN (European Norm) procedures as described in Table 1.

Twenty three groundwater samples were collected from different locations by using local piezometers and surface wells (see location points on Figure 4). A GPS is used to identify the exact location of each sampling points. They were first collected in 2008, before the beginning of the operation of recharge by TWW and three years after recharge, in 2011. As for the TWW used for the recharge, they are directly sampled from the outlet of the treatment plant by using an auto-sampler from 2008 to 2011.

Figure 3. Filling one of the recharge ponds with TWW in Korba

Table 1. Chemical and Biological Analysis Methods

Parameters	Method	Reference
Electrical Conductivity, Salinity	Electrochemistry	NF EN 27-888
Nitrate	Ion Chromatography	NF EN ISO 10304-1
Total coliform	MPN multiple-tube fermentation	NF T 90 - 413

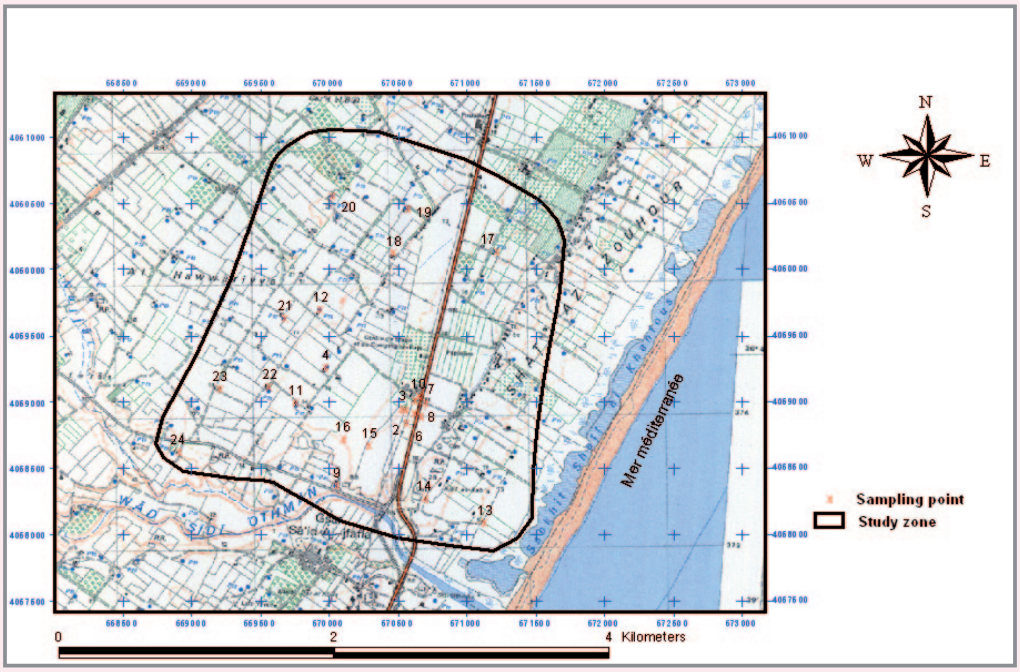

Figure 4. Sampling points location in the study area.

The results of the analysis are represented on charts drawn with ARcview/GIS software. It uses the colour system adopted by the SEQ-groundwater (quality evaluation system for groundwater) that is one of the reference used for groundwater quality and its suitability for various uses, as there is no threshold value for these waters unlike for wastewaters (Agences de l'eau, 2003). The colours ordered as blue, green, yellow, orange and red, indicate in decreasing order the capacity of the analysed water to be used for irrigation purposes, in relation to the concentration of the studied parameters like here for salinity, nitrate and total coliforms occurence.

Aquifer salinity remediation

Salinity is one of the main parameter for characterizing the quality of a groundwater. Two charts were drawn concerning the salinity distribution in the study region. The first represents the salinity of the groundwater before starting the recharge (Figure 5) and the second after three years of the aquifer recharge (Figure 6).

Referring to the distribution of salinity prior to recharge (Figure 5), it can be noted that the Northern and South-western part of the site is strongly salted: the recorded concentrations exceed 2.5 g/L and reach 7.0 g/L in the extreme North. The South-eastern part shows a relatively good quality since salinity varies between 0.5

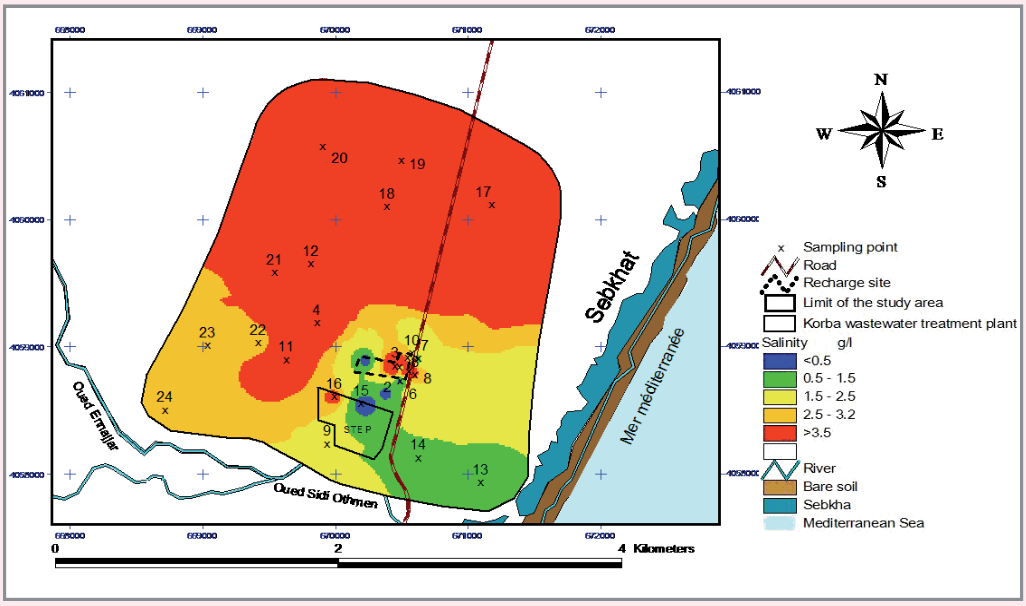

Figure 5. Salinity distribution around the recharge site before the recharge operations

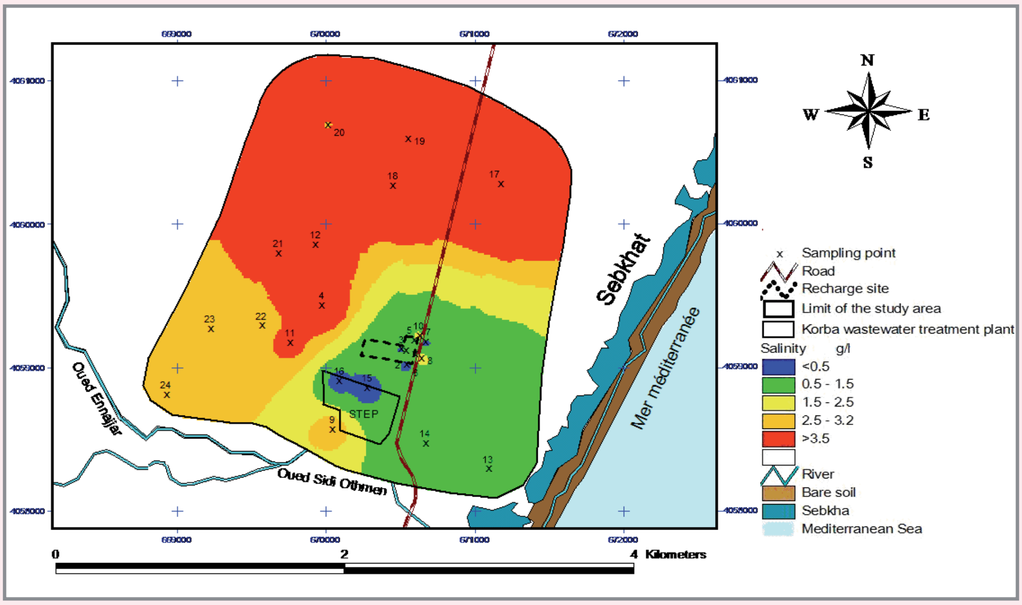

Figure 6. Salinity distribution around the recharge site after 3 years of recharge

and 2.5 g/L. The initial quality of the aquifer in this area is low regarding salinity. More than 50% of water of the study region is of bad quality in terms of salinity. These high levels of salts are ascribable to several origins. They are mainly due to the progression of salted bevel of the sea due to the multiplication of well pumping and the reduction of the refill of the aquifer by rainfall or surface waters (Ben Alaya et al., 2009). The high evaporation during irrigation with pumped water exacerbated by the hot meteorological conditions can also concentrate the salt in the waters before they infiltrate through the soil towards the aquifer.

The analysis of the TWW during the recharge period show salt concentrations ranging from 1.8 to 5.4 g/L. After three years of aquifer recharge by these TWW, changes in salinity levels had occurred in almost all points close to the recharge plant (Figure 6). There is a clear lowering of groundwater salinity near the recharge site and all the South-eastern area. The area with lower salt concentrations (between 0.5 and 1.5 g/L) extended towards the North.

Changes in Nitrate concentrations in the aquifer

The two charts representing the nitrate concentrations before and after three years of recharge are drawn respectively in Figure 7 and Figure 8.

Initially and before the recharge, more than 90% of the area show high nitrate concentrations (Figure 7), exceeding 50 mg/L, that is the trigger value set by the European Groundwater Directive (EC, 2006) for a good

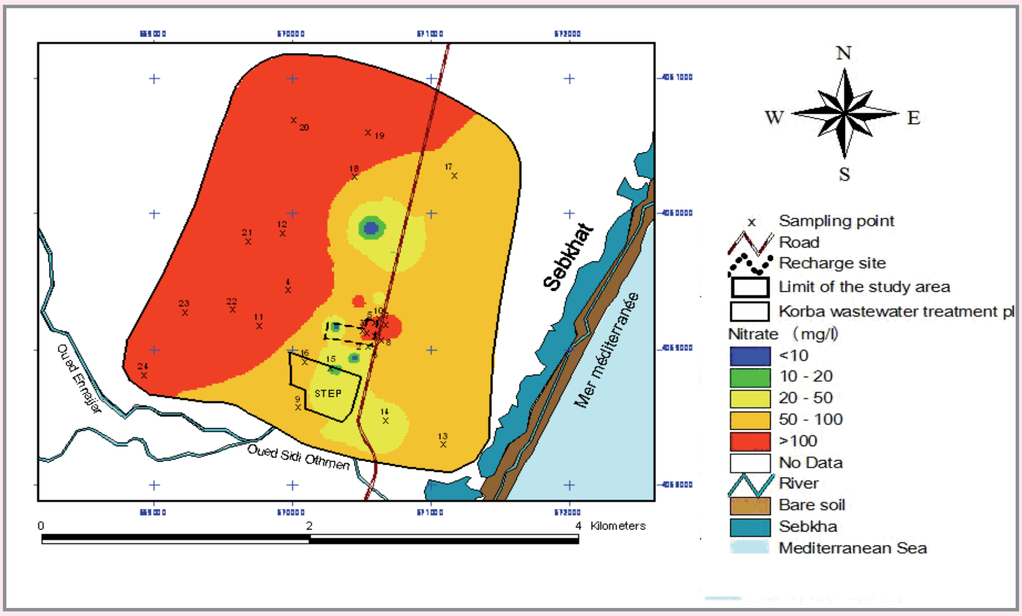

Figure 7. Nitrate distribution around the recharge area before recharge operations.

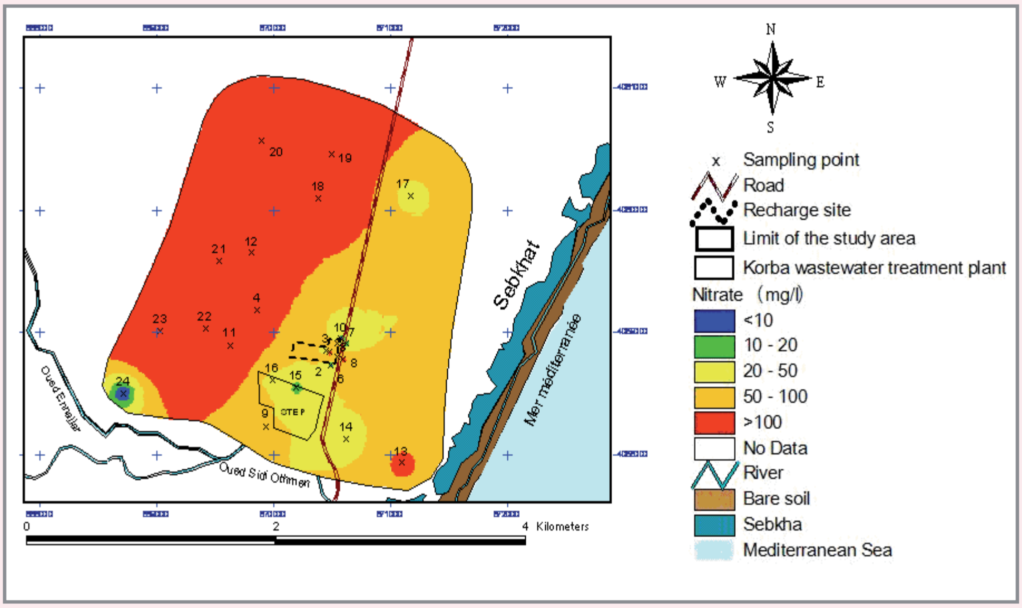

Figure 8. Nitrates distribution around the recharge area after 3 years of recharge.

chemical status of a groundwater. The most polluted area was identified in the Western side of the study area where nitrate contents exceed 100 mg/L and reach values as high as 300 mg/L. As this region is known to be mostly agricultural, these high values could be primarily due to the frequent use of artificial fertilizers in the intensive agriculture of Korba mainly vegetable crops with excessive water demand and nitrate fertilizers use. Even if the excessive use of fertilizers is considered the principal source of diffuse nitric pollution of groundwater by leaching, other point sources of nitrates like septic tanks can be accused. Furthermore, the high concentration of nitrates recorded in the groundwater near the wastewater treatment plant could be due to the infiltration of wastewater from maturation basins high in nitrogen pollution towards the aquifer.

The nitrate concentration of the TWW used to feed the aquifer is less than 5 mg/L. After three years of recharge with this TWW (Figure 8), it can be seen that there is a displacement in the nitrate contaminated area. The low nitrate concentration spot in the central area of the study region has disappeared and show now a higher nitrate concentration whereas the south-western area show new spots of low nitrate levels. There is also a slight improvement of the quality regarding nitrate near the recharge site.

The changes in bacteriological distribution

The microbial quality of water can be evaluated by the presence of indicators of contamination like the total coliform level. Their occurrence in the waters is a proof

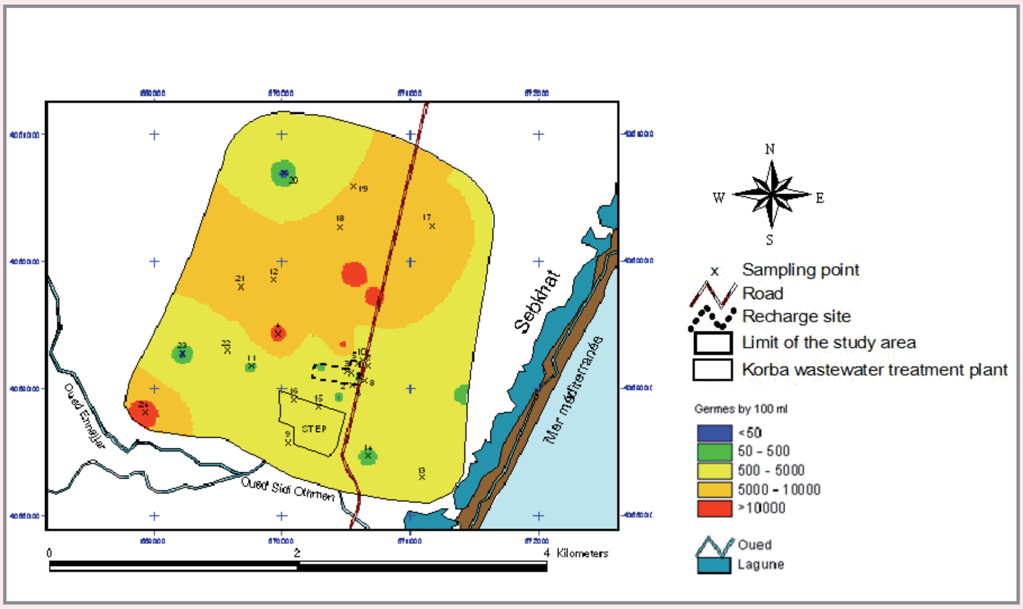

Figure 9. Total coliform distribution around the recharge site before the recharge operations

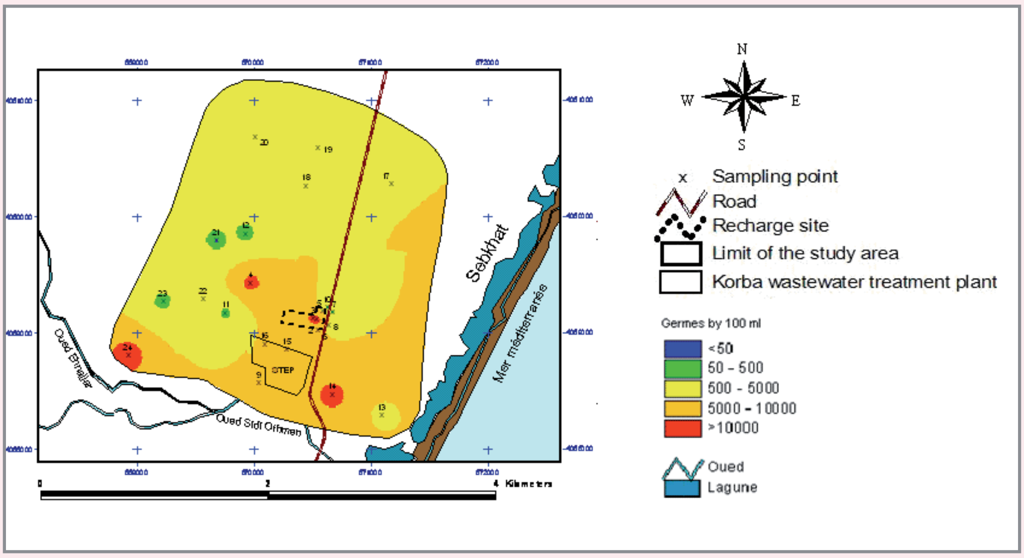

Figure 10. Total coliform distribution in the recharge site after three years of recharge

of faecal contamination and their abundance indicates a severe contamination. The chart showing total coliform distribution prior to recharge operations (Figure 9) indicates that, except for one point (point 20), all the groundwater of the study area is contaminated with more than 50 per 100mL total coliform, and cannot be used for drinking purposes. Half of the entire area has more than 5,000 total coliform per 100mL, making these waters unsuitable for animal drinking purposes and for irrigating leafy vegetables (El Ayni et al., 2012c). The origins of these contaminations are probably infiltrations from local cesspit and from the wastewater treatment plant itself.

After three years of recharge (Figure 10) with TWW having from 9,300 to 240,000 total coliform per 100 mL, the South-eastern part show a deterioration of its groundwater quality concerning bacteriological contamination from average quality (500 - 5,000 total coliform per 100 mL) to bad water quality (more than 5,000 total coliform per 100 mL). There is an improvement in bacteriological quality in the Northern area of study. These changes can be regarded as a displacement of the highly contaminated water towards eastern-south, reaching the area of recharge and the coast.

Conclusion

The comparison of the quality of the groundwater before (2008) and after three years of recharge (2011) resulting from the mixing of groundwater and infiltrated TWW showed the effectiveness of the project to cure high salinity which exceeded 1,5 g/L. The site thus played the role of a hydraulic barrier to mitigate the problem of marine intrusion and to limit its geographical extension. This evolution reveals the advantages of the project not only for limiting the intrusion of salted bevel but also for mobilizing a non conventional water resource and avoiding the residual impacts related to the rejection in the environment. Nevertheless, contamination by nitrate and bacteria remain a major problem of the aquifer and allowed the use of this water presently only for agricultural purposes. There is no net change in the distribution else than displacement of the polluted region. The pursuance of the monitoring for the future years will probably show a clearer tendency in changes of the distribution of these parameters helped by a future modelling study of the recharge operations and their evolution in terms of groundwater quality.

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Application of Membrane Bioreactor technology for urban wastewater treatment in Tunisia: Focus on treated water quality

This paper presents the physical-chemical and microbiological efficiencies of a submerged membrane bioreactor treating a domestic wastewater.

Authors: Mouna Jraou, Firas Feki, Tom Arnot, George Skouteris, Gerhard Schories, Sami Sayadi

Abstract

Water is a fundamental issue for the current and future development of Tunisia. In fact, effective water management is essential for socio-economic development and for maintaining healthy ecosystems. The balance between available water resources and the need for water supply is growing from one year to another, and the deficit in water resources is rapidly becoming larger. To fill in this gap, a strategy based on water conservation and the search of unconventional resources, such as reuse of treated wastewater, has been adopted in Tunisia. Membrane technology can make a significant contribution since membrane filtration enables the production of high quality water. The paper summarizes results of the EC-funded PURATREAT project (Contract No. 015449) and aims to assess the efficiency of submerged membrane bioreactor (SMBR) technology in domestic wastewater treatment with a view to reuse. A treated water of a high physico-chemical and microbiological quality was obtained after treatment, such that the water could be reused for unrestricted irrigation of ground crops for human consumption.

Introduction

Water is the most strategically important resource on Earth, which is essential for urban, industrial and agricultural needs. With the ever-increasing urban population and economic activities, water usage and demand are continuously increasing (Lu et al, 2010). There are many water shortage problems currently in the world, some of which are more serious than others. Rich and poor countries have quite different concerns over their water supply (Howell, 2004). The Mediterranean Region is an arid or semi-arid area, with typical rainfall ranging from 100 to 400 mm per year and 3000 h or more of sun per year (Bolzonella et al, 2010). In Africa, where large areas of the continent are already suffering water scarcity, there is a lack of simple access to drinking water at a nearby location and also a lack of any kind of sanitation for large segments of the population (Howell, 2004). To improve water availability, researchers have proposed the reclamation and reuse of municipal wastewater.

The activated sludge process is the most widely used biological treatment process for both domestic and industrial wastewaters in the world. This process

The PURATREAT project:

- Funded by the EC (Contract No. 015449), Duration 01/01/2006 - 30/06/2009.
- In total 10 partners, coordinated by ttz Bremerhaven
- More information: http://www.puratreat.com/

Key findings

- The removal efficiencies of soluble COD, Total COD, total nitrogen (TKN), and total suspended solids (TSS) reached respectively 89%, 73%, 88% and 100%.
- The treated water was free from both bacteria and viruses, hence pathogen free.
- The treated wastewater was found to be suitable for unrestricted irrigation in Tunisia, i.e. suitable for use in irrigating ground-based crops for human consumption.

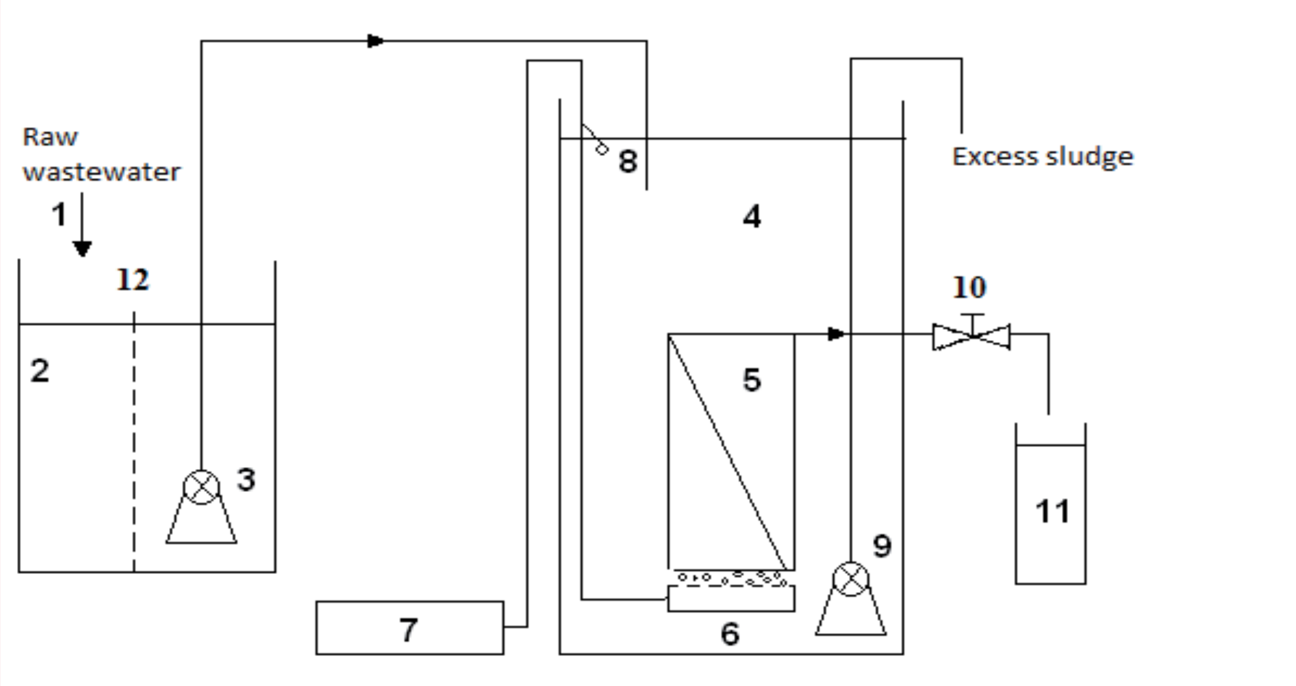

Figure 1: Schematic of the pilot MBR installation

1. Raw wastewater, 2. Feed tank, 3. Submerged pump, 4. Aerobic biological tank, 5. Kubota microfiltration membranes, 6. Air diffuser, 7. Air compressor, 8. Level detector, 9. Sludge withdrawal pump, 10. Automatic permeate valve, 11. Permeate collection tank, 12. Grit screen.

consists of biodegradation of the pre-treated influent by microorganisms in a continuous tank where oxygen supply is controlled. Following the bioreactions, the water / biomass mixture is passed to a settling tank to ensure the separation of the treated water from the biomass by gravitational setting (Wei et al, 2003; Wisniewski, 2007). The treatment efficiency is usually limited by the difficulties in separating suspended solids (Xing et al, 2000). A membrane bioreactor (MBR) is a biological wastewater treatment process in which the conventional gravity separators are replaced by microfiltration or ultrafiltration membrane modules. MBRs have become a popular biological wastewater treatment technology because they offers numerous advantages over the conventional activated sludge process, such as excellent effluent quality, a compact footprint, a more concentrated biomass, and a reduced sludge yield (Alain et al, 2008). Because membranes are an absolute barrier for bacteria, and in the case of UF also for viruses, the MBR process provides a considerable or complete level of physical disinfection (Melin et al, 2006).

This research aims to study the performance of the most widely commercialised MBR technology, that of Kubota, applied to domestic wastewater treatment in Tunisia.

Water quality analyses

Physical-chemical analyses

Chemical oxygen demand (COD) was determined according to standard method as described by Knechtel. Total suspended solids (TSS) and volatile suspended solids (VSS) were determined according to the standard methods (APHA, 1992). Total Kjeldahl nitrogen (TKN) was determined according to the standard method (Kjeldahl, 1883). Total organic carbon (TOC) was measured with a Dohrmann (DC 190) analyzer.

Microbial estimation

Total coliforms (TC), faecal coliforms (FC) and faecal streptococci (FS), total coliforms (TC), faecal coliforms (FC) and faecal Streptococci (FS) were estimated according to ISO 4832 (1991) and AFNOR (NF T90-411, 1989) water standard methods. Most probable number (MPN) determination of Salmonella (S) was carried out by modified method of Yanko et al. (1995). Helminth eggs and protozoan cysts were extracted from wastewater by sedimentation–flotation techniques.

Experimental setup

The MBR pilot plant was placed in situ at the municipal wastewater treatment plant of South Sfax (WWTP) and treated the same influent coming to the full sized plant. The system tested was a single tank submerged membrane bioreactor (SMBR) (Figures 1 and 2). The average operational volume of the MBR was 1.38 m^3. The membranes used were Kubota microfiltration membranes with a pore size of 0.4 µm, made from chlorinated polyethylene, and with an operating membrane area of 5.6 m^2. Filtration was continuous and the hydraulic head above the membranes was used to drive filtration, which was regulated by an automatic valve and a flow meter on the permeate line. Air was supplied to the filtration tank as coarse bubbles, for both membrane scouring and biomass maintenance. The gassing rate was 4.2

$m^3.h^{-1}$, which corresponds to the recommended value for Kubota membranes of 10 litres of air/membrane panel/ minute. The solids retention time (SRT) was 30 days, the average hydraulic retention time (HRT) was 1.01 days, and the average membrane flux was 12 $l.m^{-2}.h^{-1}$.

Treatment performance

Raw wastewater characterisation

The raw wastewater is pre-treated (with oil/fat, sand/grit removal and fine screening) urban wastewater of South Sfax municipal wastewater treatment plant. The physical and chemical characteristics of the influent are given in Table 1, along with the two national Tunisia standards for water discharge in the public domain, e.g. parkland irrigation or river discharge (NT 106.02), or reuse for unrestricted irrigation (NT106.03).

As pointed out in Table 1 the influent presented an inconstant composition. The COD and BOD5 concentrations are higher than the Tunisian standards NT 106.02 and NT 106.03 for hydraulic public domain and wastewater reuse in irrigation respectively. Heavy metals concentrations exceeded the required standard values for plumb (Pb), chrome (Cr) and nickel (Ni).

Table 1: Influent characteristics, and Tunisian National Standards for Water Discharge / Reuse.

Parameters	Influent waste water	NT 106.02	NT 106.03
pH	7.5 – 8.25	6.5-8.5	6.5-8.5
EC (mS/cm)	4.32 – 7.88	-*	7
TSS (mg/ l)	21 – 1700	0.03	0.03
Turbidity (NTU)	40 – 494	-	-
COD (mg O_2/l)	215 – 1134	90	90
BOD_5 (mg O_2/l)	90 – 480	30	30
TOC (mg/l)	80.4 – 428.6	-	-
TKN (mg/l)	35 – 141	100	-
NH^{4+} (mg/l)	25 – 66	-	-
NO^{3-} (mg/l)	0.4 – 2.2	-	-
NO^{2-} (mg/l)	0.03 – 31	-	-
P (mg/l)	8 – 22	-	-
Cu (mg/l)	absent	0.5	0.5
Hg (mg/l)	0.708	0.001	0.001
Pb (mg/l)	0.198	0.1	1
Cr (mg/l)	0.724	0.01	0.1
Ni (mg/l)	0.6	0.2	0.2

- indicates no restrictions regarding this component.

Figure 2: Photo of the pilot MBR installation

Physico-chemical performance

MLSS concentration

At start up the system was operated with sludge age of 15 days, which resulted in a MLSS concentration of 4.5 g/l (data not shown). After that the sludge age was adjusted to 30 days and the biomass concentration increased progressively a mean value of 9.5 g/l (Figure 3).

To maintain a biomass concentration around 9.5 g/l a regular manual sludge withdrawal was performed, which maintained the SRT at 30 days. Sudden increases or decreases in the biomass concentration in Figure 3 may be due to the time of taking a sample (immediately after biomass removal or after a shutdown of the reactor), or due to large fluctuations in the feed wastewater COD (see Figure 4).

COD removal efficiency

COD is the most important parameters studied to assess the efficiency of a wastewater treatment process. Influent and permeate COD was monitored and illustrated in Figure 4.

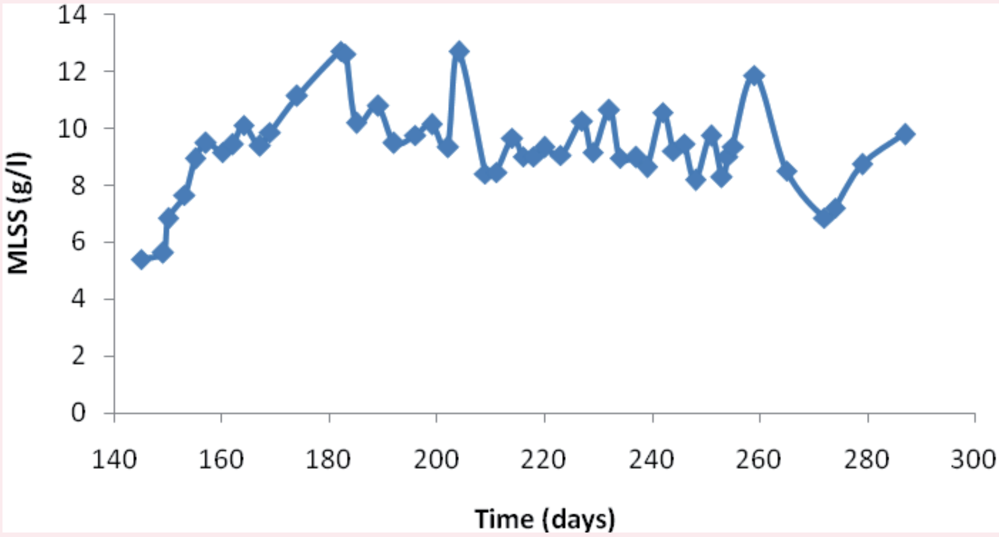

Figure 3: MLSS evolution throughout the MBR operation.

The average effluent COD was < 90 mg/l, but it should be noted that this limit was exceeded occasionally. This can be justified by an abnormal operation of the system (eg a short term flux increase, the entry of an industrial effluent...). Influent COD oscillated from 215 mg/l to 1135 g/l. Low feed COD values were due to dilution caused by rain and high values can be explained by the illegal discharge of industrial wastewater into the sewer system. Using this SMBR treatment process the COD removal efficiency averaged 96 % which is in agreement with the results of several investigators, who reported COD removal efficiencies of more than 95 % (Ogochi et al, 2000; Gander et al, 2000; Al-Malack, 2007). The permeate quality meets the standards related to reuse in unrestricted irrigation in terms of COD concentration.

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Microbiological performance

The pathogen removal efficiency of the MBR process was assessed. Several target bacteria species were used as markers of the presence of faecal contaminants or food poisoning organisms. A wide range of microorganisms were present in the raw wastewater and analysis of the permeate showed that the microfiltration membrane succeeded in retaining the selected target micro-

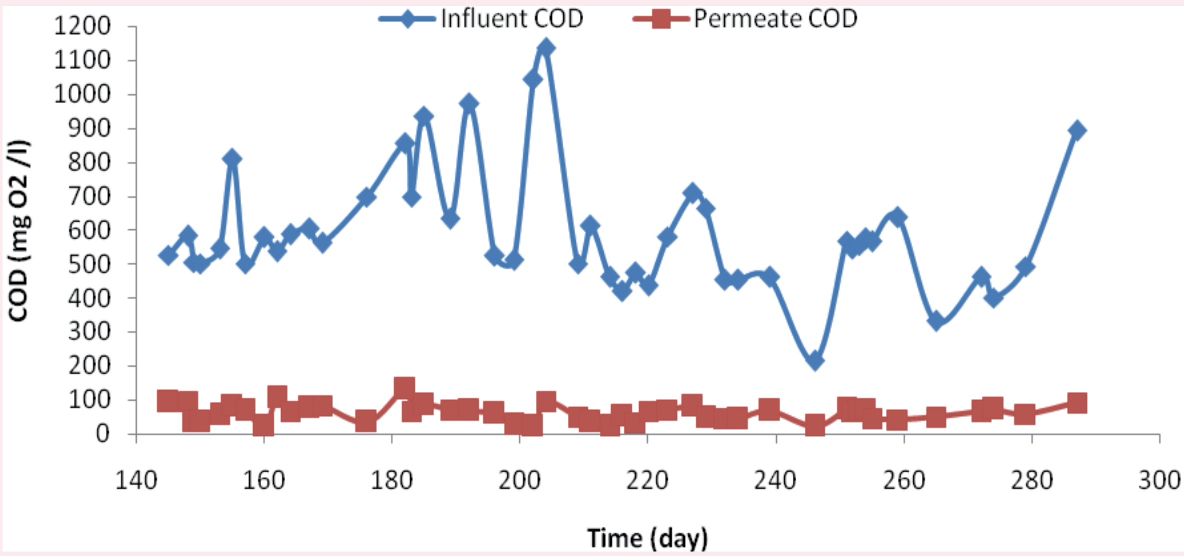

Figure 4: COD evolution throughout the MBR operation.

Table 2: Feed wastewater and permeate (treated water) microbial analysis.

Micro-organism	Influent waste water	Treated water (average)
Aerobic mesophilic bacteria (CFU/ml)*	54 x 10^7 to 90 x 10^7	40**
Total coliforms (CFU/ml)	10 x 10^5 to 53 x 10^5	0
Faecal coliforms (CFU/ml) or (MPN/ml)	34 x 10^4 to 11 x 10^5	0
Faecal Streptococci (MPN/ml)	25 x 10^5 to 25 x 10^6	0
Staphylococcus (CFU/ml)	7 x 10^2 to 13 x 10^3	0
Pseudomonas (CFU/ml)	6 x 10^1 to 6 x 10^2	0
Salmonella	Present	Absent
Helminth eggs (ova/l)	160 to 250	0
Protozoan cysts (cysts/l)	620 to 1100	0

* CFU – colony forming units
** this value is suspected as a result of recontamination of permeate as the significant majority of permeate samples did not contain any bacteria.

organisms – see Table 2. The permeate is pathogen free, and hence meets the requirements for unrestricted irrigation.

Conclusion

This study has confirmed that the biological treatment of urban wastewater by membrane bioreactor has a satisfactory performance because it gives good removal of COD and a complete retention of pathogens. The high quality of the permeate, proved by its pathogen-free character and low COD concentration, confirms its appropriateness for unrestricted irrigation of ground based human crops. The MBR system outperformed the full sized activated sludge plant, treating the same municipal wastewater, in respect of treated water quality and the opportunity for reuse.

Acknowledgement

This work was carried out under the framework of the PURATREAT Project - an EC-funded (Contract No. 015449) research initiative that aimed to study the application of Membrane Bioreactors as an alternative to the conventional treatment of urban wastewaters in the Southern and Eastern Mediterranean regions.

Description of overall project

- The objective of the PURATREAT project was to study a new approach to the operation of membrane bioreactors. This study included a comparison of three leading membrane bioreactor technologies. The operating procedure studied was aimed at minimising energy consumption and reducing maintenance costs, whilst at the same time reclaiming wastewater for reuse in irrigation. These characteristics could make membrane bioreactors working in these conditions suitable to be operated in peri-urban areas of the Mediterranean basin, where expenditure in public services is a critical factor.
- The project started on 01/01/2006 and finished on 30/06/2009.
- Partners: Technologies Transfer Zentrum Bremerhaven (TTZ), Germany (Coordiantor); Centre of Biotechnology of Sfax (CBS), Tunisia; University of Bath, UK; European Membrane Institute, the Netherlands; National Agency for Sanitation, Tunisia; University of Cadi Ayad, Morocco; University of Al-Baath, Syria; Bioazul, Spain; King Saud University, Saudi Arabia; The Inter-Islamic Network on Water Resources Development and Management, Jordan.
- The pilot trials of the MBR systems were conducted by CBS in Sfax, Tunisia.

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Design considerations for constructed wetlands in dry and hot countries

This paper discusses special considerations for design of constructed wetlands implemented in countries with dry and hot climate.

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Abstract

This paper presents examples of constructed wetlands (CWs) implemented in dry and hot countries. The design of CW treatment systems in Egypt, Palestine and Morocco is described and recommendations for application of CW technology under these environmental conditions are given.

Introduction

Constructed wetlands (CWs) are engineered water treatment systems that optimize the treatment processes found in natural environments. CWs efficiently treat different kinds of polluted water (e.g. Kadlec and Wallace, 2009). Compared to conventional systems CWs are large and extensive systems which require only low efforts in operation and maintenance. This makes CWs suitable solutions for treatments of waters in remote areas (e.g.; Headley and Nivala, 2012).

CWs have been applied in a numbers of countries with hot and dry climates (e.g. Mandi et al., 1998; Masi and Martinuzzi, 2007; Masi et al., 2010; Auborn et al., 2012). For applications in hot and dry climates usually reuse of water plays an important role and thus water loss should be minimised. This can be achieved through (Headley and Nivala, 2012):

- Selection of plants with a high water use efficiency to minimise evapotranspiration losses, and

Considerations for designing constructed wetlands in dry and hot countries

If treated wastewater should be reused water losses have to be avoided. This can be achieved by i) Selection of more efficient plants to minimise evapotranspiration losses, and or ii) Smaller footprints of the treatment system to avoid evaporation.

- When treated wastewater should be reused the treatment efficiency should match the quality needed for the specific reuse purpose limiting the treatment performances to the really needed ones. Segregation of wastewater and separate treatment of greywater can help in obtaining a higher amount of effluent with the proper quality available for the reuse.
- Vertical flow beds might be preferred to horizontal flow beds in order to minimize evapotranspiration losses due to their intrinsic shorter Hydraulic Retention Time in comparison to the other CW typologies; depending on the required effluent quality and reuse aim, VF beds can be filled with coarser sand, up to the smallest gravel available on site, in order to reduce the retention time (as well the performances in terms of pollutants removal).
- Horizontal flow beds are simpler in construction and operation as no intermittent loading is required and enhance the flexibility of the treatment whenever there is a high variation in hydraulic and organic loads, due to the higher volume of water contained in the reactor and the related buffering effect.
- Organic loads of CWs in hot countries can be higher compared to temperate climates. The available results, even though referred to few experiences, are showing that the organic load can go up to 10-30 times higher values in comparison to the usual ranges applied in Europe or North America.
- An initial commissioning phase where the water level is kept high is favoring the plantation success.

- Technology selection to optimise areal treatment efficiency and reduce evaporation from exposed water surfaces.

CWs can be subdivided into two main types, surface flow and subsurface flow CWs. In subsurface flow (SSF) CWs, in contrary to surface flow or free water surface CWs no free water level is visible. SSF CWs are subdivided into horizontal flow (HF) and vertical flow (VF) systems depending on the direction of water flow through the porous medium (sand or gravel). To prevent clogging of the porous filter material, the use of traditional SSF CWs is limited to mechanically pre-treated wastewater, which contains a low content of particulates (Kadlec and Wallace, 2009).

When treated wastewater should be reused the treated water quality should be in line with the requirements for irrigation, e.g. nutrients such as nitrogen and phosphorus would be required in the irrigation water. However, experience shows that this is often not in line with standards for wastewater treatment that require nutrient removal. Therefore there would be need for realistic standards that are related to the desired reuse.

In the paper the author‘s experiences with constructed wetland in Egypt Palestine and Morocco are presented.

Examples of CWs implemented in dry and hot countries

SEKEM farm, Egypt

The SEKEM farm wastewater and reuse work was designed to implement a constructed application of a simple, low cost, low energy and sustainable technology for the treatment and reuse of municipal wastewater through the MEDAWater European Program Support Action (Table 1, Figure 1). The treated wastewater is used for irrigation of forest trees: the irrigated land is originally desert sandy soil that is deprived from any kind

Table 1: Design data for the SEKEM farm CW

Parameter	Unit	Value
Size	PE	250
Flow	m^3/d	20
Mechanical pre-treatment	-	sedimentation tank, total volume 56 m^3
Type of CW	-	Single bed, HF
Total surface	m^2	200
Hydraulic retention time	d	2.3
Organic loading rate	g $BOD_5/m^2/d$	75
Reuse after treatment		Yes, for irrigation; The treated wastewater is reused for irrigating timber plantations as well as protecting the groundwater and improving the texture of the irrigated desert sandy soil
Special considerations during design		The design aimed to strongly reduce BOD and bacterial concentrations with the minimal HRT, reducing the total area and the evapotranspiration rate.

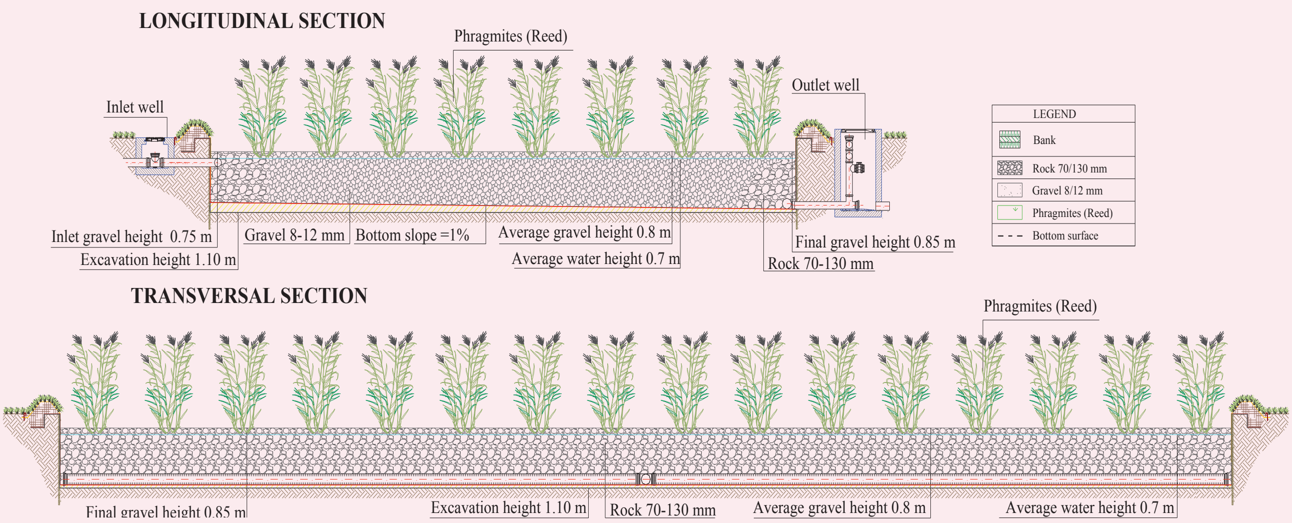

Figure 1: Schematic sketch of the SEKEM farm CW.

of nutrient elements and lack of any organic matters. The sludge is dewatered over sludge drying beds of another constructed wetland. The CW, implemented in 2007, is a horizontal subsurface flow system with a total surface of 200 m². Due to the special type of agriculture at SEKEM, organic vegetables and medicine plants grown under anthroposophic rules, wastewater will not be used on the main farm crops. It will be reused on timber plantations for packaging of the SEKEM products, which is economically very interesting.

The SEKEM farm is producing natural drugs by growing various herbs and extracting the active substances from them by an industrial cycle that ends up in the final products. It's a community, a few hundred people are living and working there and there's also a school for about 500 students.

The target area for the pilot project comprises the school of the farm, a few buildings, the campus kitchen and a laundry room. The wastewater is composed of 100 % domestic wastewater; the daily flow was calculated once from the water demand and secondly according to the number of people connected: 500 students at 20 l/day, plus 100 persons at the offices at 20 l/day, laundry plus residential houses leading to a total 15 m³/day. The SEKEM administration is going to extent the school and boarding school which would lead to a flow of approximately 20m³/day.

The design data regarding pollutant concentrations are higher than inlet monitoring data that seems to indicate a lower number of person equivalents (PE) or a higher flow (and consequently a lower HRT). However, the performance of the HF beds is good and the system permits to reach the limits of Egyptian law (Table 2).

Palestine

Oxfam Italy designed and constructed several CWs for treating greywater in some Palestinian villages in the South regions of West Bank. The greywater treatment constructions are inserted in several project founded by EC and other sponsor for the emergency support to the herders and Bedouins communities. Currently 6 CWs for greywater treatment and reuse are implemented in the

Table 2: Performance data for selected parameters for the SEKEM farm CW (average values, N = 30)

Parameters	Raw WW	Sedimentation tank effluent	Wetland Effluent	Overall Removal	Permissible limits[2]	Guidelines[2]
	mg/L[1]	mg/L[1]	mg/L[1]	%	mg/L[1]	mg/L[1]
pH	6.8-8.3	7.3-8.1	7.1-8.3	-	6.5-9.0	-
COD	800	394	174	78.2	600	400
BOD_5	357	193	103	71.3	300	150
Ammonia N	53.5	55.6	21.8	59.3	-	-
TN	94.4	69.9	43.5	53.9	-	100
TSS	217	83	33	89.8	350	250

[1] except pH
[2] The permissible limits of the primary treated wastewater for irrigating woody trees according to the Egyptian Law 48, No. 61-63, Permissible values for wastes in River Nile (1982) and Law 4, Law of the Environmental Protection (1994) - updating No.(44), (2000)

Table 3: Design data the CW treating greywater in Palestine (in total 6 CWs are operating)

Parameter	Unit	Value
Size	PE	70-120
Flow	m³/d	4-8
Mechanical pre-treatment	-	degreaser
Type of CW	-	Vertical Flow
Total surface	m²	30-60
Organic loading rate	g COD/m²/d	15-37
Reuse after treatment		Yes, for irrigation for fodder production
Special considerations during design		VF system are preferred to HF systems in order to minimize ET losses and enhance the flexibility of the treatment due to the high oscillations in hydraulic and organic daily loads

south of Hebron (see design data in Table 3 and Figure 2); 4 small CWs for wastewater treatment and reuse at household level are realized in the Gaza Strip (see design data in Table 4).

Other two interesting projects are carried on in the village of Sarra (Nablus) and Hajja (Al Qalqilya). The project „Making wastewater an asset: increasing agricultural production introducing irrigation by non-conventional water sources“ is managed by the NGOs GVC, PHG and UAWC and is financed by the EU (Contract number DCI-FOOD/2010/254-819). The final aim of the WWTPs realisation, over the obvious strong reduction of health risks linked to the presence of untreated wastewater in the villages, is to create a new source of water for irrigating the olive trees and increase the productivity and the related local economy. The approach using natural treatments such as CWs is still quite new in Palestine and mainly tested before on small scale applications or pilot plants; there are also some failed experiences

Table 4: Design data the CWs for treating wastewater treatment at household level, Gaza, Palestine (3 CWs currently operating)

Parameter	Unit	Value
Size	PE	10-20
Flow	m^3/d	0.5-1
Mechanical pre-treatment	-	three chamber septic tank
Type of CW	-	Horizontal flow
Total surface	m^2	30-60
Organic loading rate	g $COD/m^2/d$	15-37
Reuse after treatment		Yes, for irrigation for fodder production
Special considerations during design		HF type was selected prior to simplify the construction activities and the recovery of the materials; moreover Gaza is very flat and a VF feeding by gravity is often impossible. Finally the CW plants are designed for household level and realized closed to the buildings where a lot of children play every day: the HF systems avoid any contact with wastewater.

Figure 2: Greywater treatment CW in Al-najada, Hebron district, Palestine.

in the country mainly due to bad design or inaccurate realisations.

In Sarra (about 3500 PE) a new WWTP will be constructed (Table 5, Figure 3). The plant is composed of a pre-treatment with mechanical screen, a primary treatment with two tanks Imhoff in parallel, a secondary treatment using a 1st stage with vertical subsurface flow system (6 basins in parallel, 1500 m^2); 2nd stage with horizontal subsurface flow system (6 basins in parallel, 3000 m^2). The system will be equipped with slude drying reed beds for the sludge extracted from the Imhoff tanks.

The system in Hajja is a 2 stage VF + HF CW (after a primary grid and a primary treatment) that rehabilitated an existing CW plant for a population of around 1000 PE and it's designed in order to have the possibility to be doubled with the realisation of other two equal line of treatment as soon as the remaining part of the population (up to 3000 PE) will be connected to the treatment system (Table 6).

In both cases the effluent will be stored in a pond and reused for olive tree irrigation. These 2 systems will provide a useful example for possible replications in the numerous similar situations in the country.

Table 5: Design data the CW at Sarra village, Nablus district, Westbank, Palestine.

Parameter	Unit	Value
Size	PE	3500 (2022 scenario)
Flow	m^3/d	350
Mechanical pre-treatment	-	automatic screw screen + 2 Imhoff tanks in parallel
Type of CW	-	6 VF bed and 6 HF bed in series
Total surface	m^2	4500 (1500 VF, 3000 HF)
Hydraulic retention time	d	2
Organic loading rate	g $COD/m^2/d$	VF 1st stage: 197 HF 2nd stage: 20 Overall: 65
Reuse after treatment		Yes, for olive three irrigation
Special considerations during design		Due to the limited available area, a hybrid system was provided with a VF 1st stage filled with pea gravel (according to French systems guidelines) designed for high loading rate and fed by gravity using siphon devices. This design choice accomplished also with the goals to reduce ET losses. A final pond will be realized to store the treated water and to refine its quality.

Table 6: Design data the CW at Hajja village, Qalqilya district, Westbank, Palestine

Parameter	Unit	Value
Size	PE	1200 (2022 scenario)
Flow	m^3/d	120
Mechanical pre-treatment	-	three chamber septic tank + manual grid
Type of CW	-	VF and HF in series
Total surface	m^2	1590 (615 VF, 975 HF)
Hydraulic retention time	d	2.4
Organic loading rate	g $COD/m^2/d$	VF 1st stage: 138? HF 2nd stage: 8 Overall: 53
Reuse after treatment		Yes, for olive three irrigation
Special considerations during design		Also in this case a hybrid system was provided with a VF 1st stage filled with pea gravel (according to French systems guidelines) designed for high loading rate and fed by gravity using siphon devices. This design choice accomplished also with the goals to reduce ET losses. A final pond will be realized to store the treated water and to refine its quality.

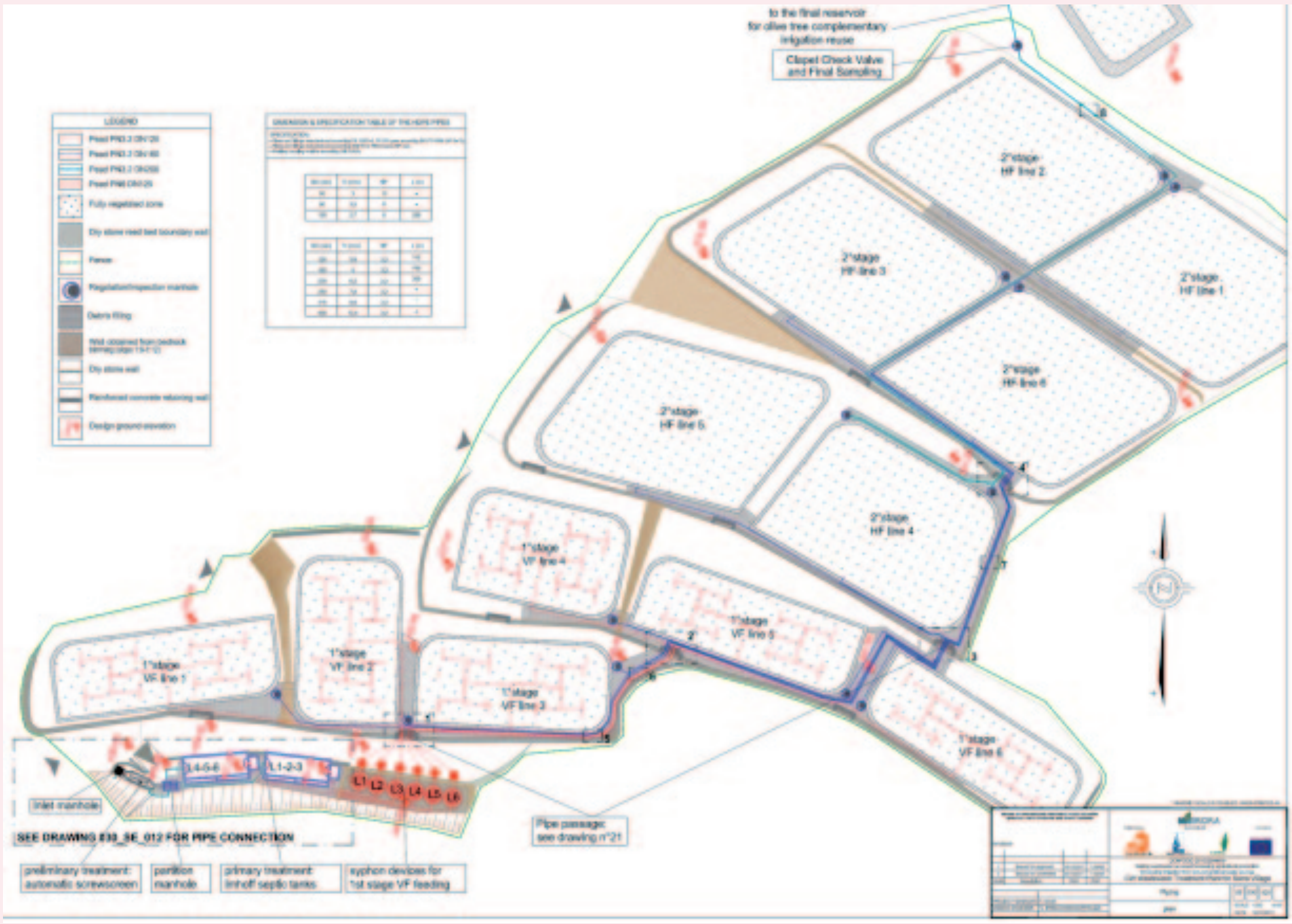

Figure 3: Schematic sketch CW at Sarra village, Nablus district, Westbank, Palestine.

Table 7: Design data the CWs for treating greywater treatment at El Attaouia, Morocco

Parameter	Unit	Value
Size	PE	100
Flow	m³/d	60
Mechanical pre-treatment	-	automatic screw screen + 2 Imhoff tanks in parallel
Type of CW	-	6 VF bed and 6 HF bed in series
Total surface	m²	4500 (1500 VF, 3000 HF)
Hydraulic retention time	d	0.4
Organic loading rate	g COD/m²/d	40
Reuse after treatment		Yes, for olive three irrigation
Special considerations during design		Due to the limited available area, a hybrid system was provided with a VF 1st stage filled with pea gravel (according to French systems guidelines) designed for high loading rate and fed by gravity using siphon devices. This design choice accomplished also with the goals to reduce ET losses. A final pond will be realized to store the treated water and to refine its quality.

El Attaouia, Morocco

The pilot activity in El Attaouia is a partnership between the project "Sustainable concepts towards a Zero Outflow Municipality (Zer0-M)", mainly the Moroccan partner Institut Agronomique et Vétérinaire Hassan II (IAV Hassan II) in Rabat and the Municipality of El Attaouia. Zer0-M is a project in the Euro-Mediterranean Regional Programme for Local Water Management (MEDA Water programme), funded by the European Commission and the national partners of the project (Masi et al., 2010).

The construction of the wetland treatment shall help to ease the difficulties in water and wastewater management faced by the fast growing rural centre of El Attaouia, a town in a dry climate with constantly increasing water consumption and very limited financial resources for the supply and sound evacuation of the amounts of water required.

The pilot plant should provide the possibility for safe reuse of greywater in outside uses (landscaping of green areas). A two stage CW treat the greywater of a Hamman to a degree to make it useable for landscaping. The filter beds are made of concrete, the first stage sitting more or less on the ground, the second completely buried. The level difference between the two beds is used to operate the batch feeding system. The first stage CW consists of a more or less continuously fed HF coarse filter. The second stage consists of a VF bed filled with fine material with batch feeding. Both beds are planted with reed (*Phragmites communis*).

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Notes

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