WASTEWATER REUSE FOR AGRICULTURAL IRRIGATION IN PERI-URBAN AREAS IN DEVELOPING COUNTRIES:

PRACTICES, CHALLENGES AND OPERATIONAL SOLUTIONS

Egypt - Agriculture in the Nile Delta © Condom, 2015

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COSTEA Pour une irrigation durable

SUMMARY

Today, wastewater reuse is an under-exploited option to cope with the challenges of water deficits and the degradation of environments and sanitary conditions. The implementation of sustainable and safe wastewater reuse projects requires that stakeholders, whether managers or funders, possess the key elements so that they anticipate the risks and propose solutions that are suitable for the uses and territories.

Agriculture is a sector that has long valued raw wastewater, without any planning. Today, in both the North and South, the reuse of wastewater for agriculture is of interest to local politicians and decision-makers. There is a simultaneous need for water treatment projects including an emerging agricultural reuse component and to develop legal, regulatory and institutional frameworks in addition to supporting and strengthening the capacities of all stakeholders.

Based on the experience feedback, up-to-date and latest knowledge and analyses of practices, obstacles and operational solutions, this report guides and directs both readers and actors in their project. It provides recommendations and perspectives for the future along with the necessary knowledge, methodology or technology developments.

This report, which is focused on agricultural practices in peri-urban areas in developing countries, addresses the challenges of (i) safeguarding raw wastewater reuse chains; (ii) choosing suitable treatment chains; (iii) impacts on resources; (iv) political, institutional and regulatory processes; and (v) economic and environmental assessments using decision-making tools.

PREAMBLE

This study is the result of work carried out within the framework of the *Reuse of wastewater in agriculture* project. It is rooted in the Technical and Environmental Performance focus of COSTEA[1], the Scientific and Technical Committee for Agricultural Water.

COSTEA is a network of actors financed by the AFD and led by the AFEID. Its aim is to contribute to the development of irrigation policies in the AFD's partner countries so that they adopt the best institutional, technical and economic options for mobilizing water resources in order to improve productivity and reduce the vulnerability of family farms to Climate Change, with no negative environmental externalities and in accordance with the principles of integrated water resources management (IWRM).

COSTEA's overall objective is to update and strengthen (i) the alignment of experiences, tools and actions, (ii) the skills and capacities of AFD's partners, actors in agricultural water policies in the countries in which they operate and the French actors who work alongside them.

Within this context, it was agreed to carry out a study on **wastewater reuse for agricultural irrigation in peri-urban areas in developing countries**.

The study was conducted in 2015 by the consulting firm Ecofilae[2], and is based primarily on the firm's expertise, **additional bibliographic research and exchanges with resource persons**. The study was designed, guided and monitored using a collective approach involving COSTEA's partner institutions: the AFD, IRSTEA, BRL, CACG, SCP, Swelia network and Transfert LR. A monitoring committee comprised of representatives from these institutions met at the start, at an intermediate stage and at the presentation of the report, to comment, build on and validate Ecofilae's proposals. The study was originally written in French.

The AFEID, in collaboration with The Working Group on use of Poor Quality Water (WG-PQW) of the International Commission on Irrigation and Drainage (ICID), organized a roundtable called "Wastewater reuse: now is the time for solutions!", to provide an additional opportunity to give input into the study through current international experiences. This roundtable was held on 13/10/2015 in Montpellier, as part of the 2015 ICID "Innovate to improve irrigation performance" conference, hosted by Nicolas Condom[3], Akica Bahri[4] and Samia El Gendy[5].
All interventions can be consulted on the website icid2015.sciencesconf.org.

The acronyms RWW (raw wastewater), TWW (treated wastewater), RWWR (raw wastewater reuse), TWWR (treated wastewater reuse) and WWTP (wastewater treatment plant) are used often in this report. The definitions of "raw wastewater" and "treated wastewater" used in this report are presented in the introductions of Chapters 1 and 2 of Part 2, respectively.

1 - Financed by the French Development Agency (AFD) and led by the French Association for Water, Irrigation and Drainage (AFEID), the Scientific and Technical Committee for Agricultural Water (COSTEA) is a community of experts with highly diverse geographical roots, skills, institutions and trades, working together on irrigated agriculture and with the aim to help improve the effectiveness of policies and irrigation projects. www.comite-costea.fr

2 - www.ecofilae.fr

3 - Founding President of Ecofilae

4 - Professor at the National Agronomy Institute in Tunisia (INAT)

5 - President of The Working Group on use of Poor Quality Water of the International Commission on Irrigation and Drainage

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INTRODUCTION

OBJECTIVES AND APPROACH

The objectives of this study are to **capitalize on current experiences, gather new knowledge and analyse the practices, challenges and operational solutions so as to accompany users-actors** in agricultural wastewater reuse by enabling them to create a more evident link between the availability of an urban water resource and the water needs of a peri-urban agricultural area to be irrigated.

Therefore, it provides:

- **an inventory** (not exhaustive and constrained by the availability of information in the bibliography) of agricultural wastewater reuse **projects and experiences**, all over the world and at different scales (country, territory, or project), with an analysis of the **obstacles these experiences have faced**. This experience feedback, which are sources of inspiration for the reader, illustrate specific points throughout the report;
- **a set of solutions and levers of action** (technical options and latest methodological developments) for the identified problems and obstacles, with a view to better carry out water reuse projects;
- **a breakdown of the deficiencies that currently constrain the dynamics** of wastewater reuse in agriculture and which therefore open the field for new developments and suggest new directions for research.

As a result, this study provides **operational** material as part of the ongoing work. It is organized based on an integrative **methodological framework that focuses on five main issues** that currently affect the development of wastewater reuse. Each of these issues is the subject of a dedicated chapter that is organized based on the **opportunities, threats, advantages, disadvantages, gaps and areas to be investigated** for future developments, with a continual return to the field to benefit from what has been learnt from projects carried out all over the world.

As a result, this entire work was based on **two complementary approaches, capitalizing on what already exists and the analysis**.

STUDY DESIGN

The sources of water and uses considered in this study are specified below:

- **Types of water:** the study examines **urban and domestic raw (RWWR) and treated wastewater reuse (TWWR)**. When appropriate, other types of effluent and sludge are discussed, but they are not thoroughly analysed;
- **Type of use: irrigated agriculture** is the main use in the study. However in the countries and projects considered, other are sometimes other associated uses: the watering of almost all golf courses in Tunisia, the watering of green spaces in some Moroccan cities, etc. Reuse and industrial recycling were not considered here;
- **Level of control of uses: only direct or indirect reuse projects, in peri-urban areas**, with a minimum degree of **planning or control** have been described. However, many of these projects are developed on existing unplanned and uncontrolled RWWR practices.

Analytical scales and geographic targeting of the study
2 scales of analysis are used for the experience feedback.

The **country scale** (used in five country summaries: Tunisia, Morocco, Jordan, Egypt and the Palestinian Territories) makes it possible to understand the national logic regarding reuse, to provide consistent Government-Lender dialogue and to reflect on how to approach agricultural waste reuse projects within these contexts (national strategy, regional planning, local project).

The city or project scale, with an analysis of the reuse chains whenever possible, i.e. from the source of the raw wastewater until its use in agriculture, makes it possible to illustrate the obstacles, implemented solutions and benefits in the actual conditions.

The ultimate goal of the study commissioned by COSTEA is to accompany French stakeholders and their partners in the South in their discussion on agricultural wastewater reuse; in addition, special attention is given to the countries in COSTEA's "priority" regions which are the **Mediterranean, West Africa and South-East Asia** (with fewer documented cases for the latter two regions), but without precluding the analysis of experiences from other regions.

STUDY CONTENT AND ORGANIZATION

The report is divided into 2 parts.

PART 1 first provides the general context by presenting a **brief overview of peri-urban agriculture** in developing countries and introducing the drivers and objectives that encourage agricultural reuse in these countries. Based on this general context, a summary of the lessons learned at the national and local scale illustrates the diversity of the situations. These experiences are detailed in the **Country summaries** and **Project summaries** at the end of the report. These lessons learned are then mobilized to underpin the points of the analysis in Part 2.

PART 2 is organized into **5 chapters**, each focusing on a major issue illustrating one of the major challenges of reuse. The common thread of this part is a progressive pathway that aims to address the various components of sustainability in an agricultural wastewater reuse project (safety, cost-effectiveness, feasibility, acceptability, organizational efficiency) as defined in Figure 2.

However, the chapters are written in such a way that they can be read and understood independently. The chapters address questions on raw wastewater reuse (Part 2 - Chapter 1), the choice of treatment chains (Part 2 - Chapter 2), the impacts of reuse on resources (Part 2 - Chapter 3), organizations and institutions (Part 2 - Chapter 4), and assessment tools (Part 2 - Chapter 5). Some chapters repeat material from other chapters. This is to be able to fully address the specific question posed in each chapter, without the reader having to refer back to previous chapters. In this way, it is easier to use this report as a guide.

Last, recommendations are proposed as a conclusion.

Thailand - Local productions at a market in Bangkok © Coulon, 2017

PART 1

GENERAL CONTEXT AND EXPERIENCE FEEDBACK FOR WASTEWATER REUSE IN AGRICULTURE IN DEVELOPING COUNTRIES

PERI-URBAN AGRICULTURE IN DEVELOPING COUNTRIES AND ASSOCIATED PRACTICES

Peri-urban agriculture, like urban agriculture (which is sometimes called "interstitial" agriculture), **is common and has always existed** in the large urban centres of developing countries. The peri-urban sphere of influence is characterized by facilities to access services and markets as well as strong pressure for the use of resources (Moustier P. (ed.) 1999). Thus, this activity plays a major role in the **supply** of foodstuffs **to cities** and also in **maintaining local economic activity**. It mainly involves skilled trades, such as market gardening, small-scale animal husbandry including poultry farming and fish farming, in addition to related post-harvest activities.

Recycling practises

Urban **organic waste recycling** activities have developed in these peri-urban areas: in addition to wastewater, household waste in Brazzaville, livestock manure in Bissau, etc. They have enabled farmers to benefit from fertilizer resources at a low cost, although these practices, often uncontrolled, create high health and environmental risks. Pesticides are also often used unnecessarily when farmers have access to them (Paule Moustier 1997).

Related crops

Peri-urban market gardening, compared with rural agriculture, encourages the production of **perishable crops and temperate-type crops** (salads, aubergines, cabbage, carrots, etc.) as it is easier to have access to fertilizers and technical support in urban areas. Non-perishable products that are more suitable for extensive production are more attractive in rural areas (Paule Moustier 1997).

A study on four cities in South-East Asia (Hanoi, Ho Chi Minh City, Vientiane, Phnom Penh) highlighted the **crop diversification** in the region: market gardens, rice farming, fish farming and other crops (Bon Hubert (ed.) 2004).

Short crop cycles are favoured in these systems: certain crops are harvested in under 60 days, a lot of fertilizers are used and the production is denser per m2 than in rural areas. **High value-added production** is encouraged, thus enabling peri-urban farmers to have better incomes overall than in rural areas. The **surface areas per farmer are very variable** and can range from a few hundred, even tens, of m^2 to a few hectares.

Irrigation practices

Peri-urban crops are **often irrigated** and the available resources used are often impacted by urban activities.

Irrigation techniques are generally rudimentary and independent of the quality of the resources used. Manual irrigation using containers carried or transported from the source to the plot (a common practice in West Africa) and **gravity-fed irrigation** using furrows or via submersion illustrate that irrigation and agriculture are often poorly controlled with high health and environmental risks.

Localized irrigation is often promoted and heavily subsidized with the goal to reduce poverty and increase water efficiency within contexts of water scarcity. Numerous studies have highlighted the benefits of these technologies in terms of yields, income and food safety.

When implemented, localized irrigation requires control of the water quality and adaptation of the equipment (filtration, cleaning and equipment replacement). The transition toward this type of system is seen as a stage of modernization by farmers and may incite them to make future investments or to turn to higher value-added and more water-efficient crops. Nevertheless, the adoption of these technologies is sometimes limited by the long-term benefits they provide when farmers are looking for more immediate benefits (e.g.: Morocco).

Economic benefits

Most of the time, peri-urban agriculture is a **full-time activity** for a large part of the urban population as **10 to 80% of the urban population in Africa devote themselves to it**, for self-consumption, as well as for sale (Paule Moustier 1997). From an economic point of view, the goal of this activity is to ensure a decent income for farmers and to satisfy the demand in cities. It is therefore of crucial importance for urban incomes and food within a context of strong demographic imbalance between cities and the countryside and impoverishment in the urban environment.

A constantly changing activity

Often, peri-urban agriculture is **not taken into account by agricultural policies and urban planning**. Because this water is underground, farmers in many cities do not receive any public aid and are outside of government control; therefore, practices are not controlled and are instead moving more toward "do-it-yourself" systems. Furthermore, farmers often operate without a permit on their **land, so land ownership is very precarious**, especially when faced with urban pressures. Procedures to protect against expulsion are rare.

The irreversible expansion of urban areas, marked by sudden transformations and population growth, successively transforms rural lands on the outskirts of cities into peri-urban agriculture areas and then into urbanized areas where interstitial spaces sometimes exist for urban agriculture. This evolution characterizes the precariousness of peri-urban agricultural areas, which are referred to as areas in constant transformation (Paule Moustier 1997). The result is the **problem of the economic and agronomic sustainability of agricultural activities in peri-urban spaces** (Moustier P. (ed.) 1999).

WASTEWATER REUSE IN PERI-URBAN AGRICULTURE IN DEVELOPING COUNTRIES

One solution to the shortage

In order to cope with water shortages, there is one set of levers (Figure 1) that act on supply (storage, desalination, etc.) and other levers that act on demand (modernization of irrigation systems, awareness raising, etc.). These levers may sometimes compete with each other, and sometimes they are complementary and implemented in stages, guided using an approach based on economic rationality and ease of implementation.

TWWR is a very effective lever, but is by far the most complicated to implement as it requires a **complete paradigm shift**; the approach must be **multidisciplinary, involve multiple actors**, address both the national and local context, and be specific to each context (see the analysis in the 2012 Blue Plan Papers). This complexity drives the actors to delay these projects and to instead look at other more conventional options to solve supply/demand adequacy problems.

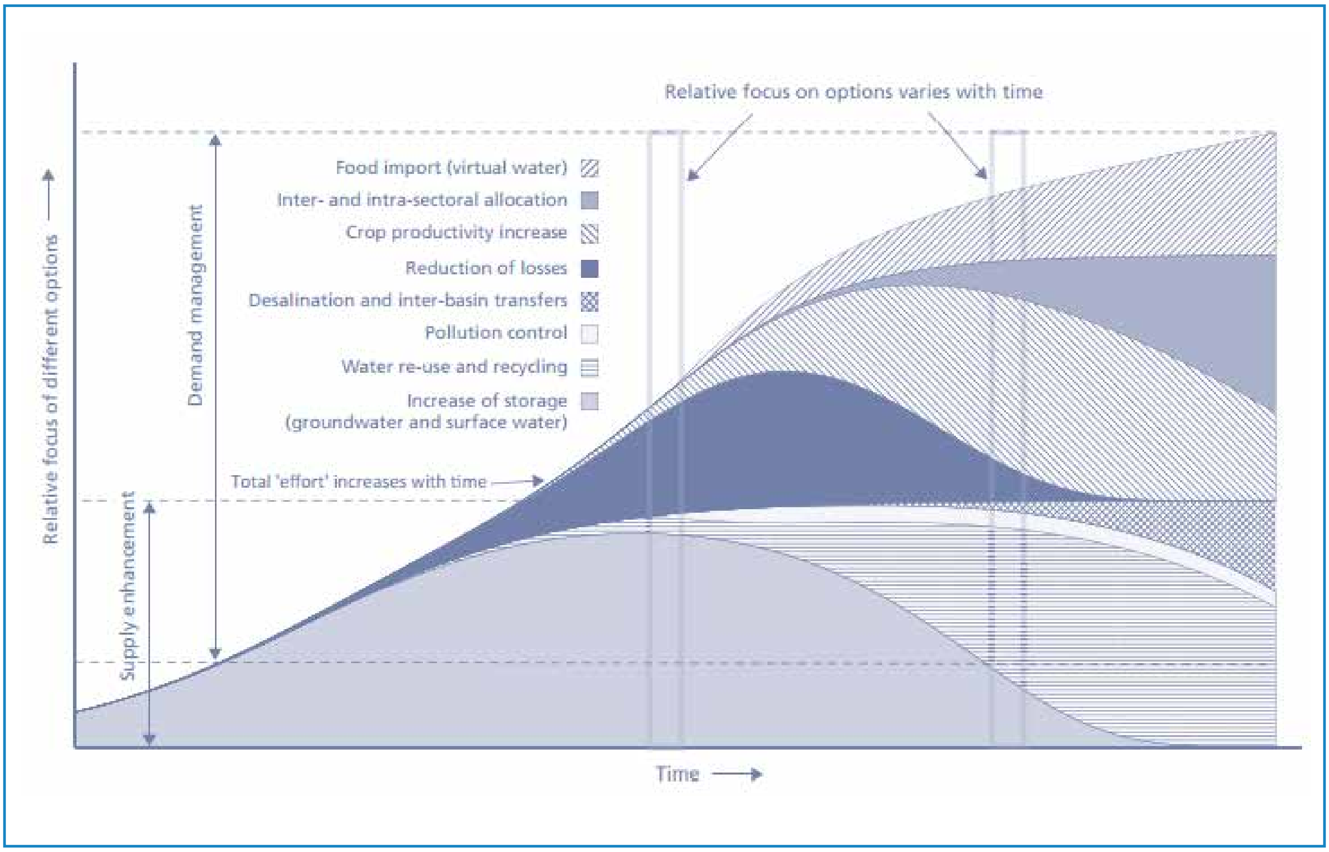
Drivers and objectives

Raw wastewater reuse (RWWR) is a very old practice in the peri-urban areas of many cities in developing countries. **Most of the planned projects for treated wastewater reuse (TWWR) are developed on a pre-existing system of uncontrolled reuse, which is often anarchic and spontaneous in terms of the agricultural benefits from raw wastewater.**

In developing countries, it is not always possible to treat large quantities of raw wastewater due to **limited and inadequate collection and treatment infrastructures**. However nowadays, the possibility to reuse treated wastewater is staring to be integrated into each new treatment station construction project, in a somewhat clear manner depending on the country.

The **main driving forces** behind the implementation of **controlled and planned TWWR projects** in these specific contexts are:

• **the high population growth** in urban and peri-urban areas



RE 1: Schematic representation of the different options in the agricultural sector to cope with the various levels of water scarcity – FAO, 2012

(often uncontrolled) which together result in a **decrease in water resources** (water resource per capita ratio – Falkenmark Water Stress Indicator) thereby increasing the effects of **climate change**, and a **growing demand for food**, providing a fresh look at wastewater which is no longer viewed as waste to be disposed of but as a local resource that can have value in a productive system;

- a demand for **quality products** without health risks motivating the control and improvement of the (raw) water quality used by peri-urban farmers;
- the increasing **price of conventional water resources** all over the world.

As a result, in developing countries, **TWWR projects are combined with reclamation development and control** (opportunity provided by installing a station), as well as with aspects of **soil salinity management** and **water resource management** (factors motivating water treatment). These projects then have multiple objectives:

- to make up for the deficit in terms of raw wastewater treatment/collection;
- to limit environmental (pollution and salinization of groundwater and surface water as well as soils) and sanitation risks linked to discharge and uncontrolled raw wastewater reuse in peri-urban areas;
- to provide an additional water resource, of sufficient quality for irrigation;
- to preserve other resources in terms of quantity, for other uses (groundwater, drinking water, surface water, etc.);
- to preserve and develop quality peri-urban agriculture.

LESSONS LEARNED AT VARIOUS SCALES AND FOR VARIOUS REUSE APPROACHES

The presented cases, which could not be investigated in the field within the framework of this study, have variable descriptions due to a lack of data and published experience feedback. National and local experiences are summarized here by extracting their highlights, and details are given in the Country Summaries and Project Summaries at the end of the report.

Analysis of the national strategies

The goal of this experience feedback is to assess and compare the maturity of five countries in the **Middle East North African (MENA) Region** with respect to the dynamics of wastewater reuse, by highlighting drivers and contextual factors, remarkable experiences, constraints and solutions provided, as well as challenges for the future. These five countries all share a relatively similar context in terms of water scarcity, but have a wide range of types, levels of development and political integration of TWWR. Briefly:

- In **Tunisia** (Country 1) the benefits of TWWR for agricultural, environmental or even industrial purposes are clearly evident: much research and development work has been and is still being carried out there (Country 1). All the golf courses in the country are irrigated with TWW, groundwater recharge has also been implemented.
- In **Morocco** (Country 2) the water deficit and the desire to control and limit the old RWWR practices are the main drivers for TWWR projects. Numerous projects are being developed but applications are limited.
- **Jordan** (Country 3) has a very high reuse rate: treated wastewater is reused indirectly after dilution with water from a reservoir. Sludge management is still a major problem.
- In **Egypt** (Country 4) wastewater management is intrinsically linked to water from the Nile encouraging indirect reuse. Agricultural practices and crops have been adapted to the quality of the water. Numerous direct TWWR projects for non-food production are being implemented. The regulations are still very strict in terms of authorized uses.
- In **Palestine** (Country 5) there is little experience with TWWR as it is difficult to implement in extreme water scarcity contexts.

Analysis of local and project experience feedback

12 local experiences and projects are described in the **Project Summaries** at the end of the report, from the source of the wastewater until its use, and sometimes even to the future of these waters in the environment. This experience feedback presents the obstacles encountered (during the implementation and afterwards) and the solutions provided.

All these experiences are projects that are already in place (apart from the NGEST project in Palestine and the project for the city of Bogota in Colombia, in progress).

The case of **Accra in Ghana** (Project 1) is fairly representative of what happens in many large cities in Africa: the treatment capacity is very low and raw wastewater, often mixed or partially diluted (rainwater), is used to irrigate vegetable crops in urban and peri-urban areas. More areas are irrigated with wastewater than those irrigated with conventional water. This water makes it possible to develop diversified, labour-intensive agriculture, over small surface areas, and close to the households that consume them. Some farmers are able to implement health protection measures (the WHO's multi-barrier approach) (Table 2).

The city of **Dakar** (Project 7) and other neighbouring cities in **Senegal** are gradually remedying this phenomenon by planning and controlling TWWR. For example, in the Pikine District of Dakar, where close to 160 farmers irrigated 16 ha using raw wastewater, improvements made to the reclamation system and its expansion today allow for irrigation with treated wastewater. Consequently, these TWWR practices limit soil and groundwater salinization processes, and add an economic value of 3% to the wastewater produced by the city.

In **Hanoi** (Thanh Tri District) (Project 3) in **Vietnam**, water purification is carried out through aeration basins, followed by dilution. As in Accra, the practices of farmers, which mobilize health protection measures, make it safer to reuse this poorly treated wastewater. Farmers are fully committed to making sure the project succeeds since they are responsible for operating part of the chain.

TABLE 1: Presentation of local reuse experiences - Ecofilae

CITY, COUNTRY	ORIGIN OF THE WATER	TREATMENT	VOLUMES OF WATER REUSED	TYPE OF REUSE	AGRICULTRUAL PRODUCTIONS	MORE DETAILS
Accra, Ghana	Primarily domestic water (via streams, channels)	No treatment	?	Direct and indirect (mixture and dilution)	Primarily market gardens	Project 1
Faisalabad, Pakistan	Mix of domestic water and industrial water	No treatment	?	Direct	Market gardens	Project 2
Hanoi, Vietnam	Domestic water	Minimal treatment (small wetlands)	?	Direct	Aquaculture, market gardens, rice	Project 3
Settat, Morocco	Domestic water	Lagooning	2.04 mm^3/year	Direct	300 ha of wheat, fodder, maize, berseem, potatoes, olive trees	Project 4
Ouagadougou, Burkina Faso	Mix of domestic water and industrial water	Lagooning	16 mm^3/year	Direct	Market gardens	Project 5
Delhi, India	Domestic water	Activated sludge	37 mm^3/year	Direct	Market gardens, horticulture	Project 6
Dakar and surrounding areas, Senegal	Domestic water	Lagooning + activated sludge	?	Direct	Market gardens, horticulture	Project 7
Korba, Tunisia	Domestic water	Lagooning + activated sludge	0.55 mm^3/year (groundwater recharge)	Indirect: agricultural groundwater pumping	Market gardens, fruit	Project 8
Northern Gaza Strip, Palestinian Territories	Domestic water	Activated sludge on one side (Jabaliya) and lagooning on the other (Beit Lahia) + infiltration ponds	2017: 54,000 m^3/d 2025: 69,000 m^3/d (agricultural pumping)	Indirect: agricultural groundwater pumping	Arboriculture (citrus, almond trees, olive trees), fodder, fruit	Project 9
Harare, Zimbabwe	Mix of domestic water and industrial water	Biotrickling filters	48,000 m^3/d	Direct (by mixing with sludge)	Grazing land	Project 10
Bogota, Colombia	Domestic water	Primary and secondary treatment	?	Direct	?	Project 11
Hadba El Khadra, Libya	Mix of domestic water and industrial water?	? + Filtration sur sable	110,000 m^3/d	Direct	Fodder, vegetables and windbreak plantations	Project 12

After having tested the irrigation of their crops with TWW, farmers in **Faisalabad, Pakistan** (Project 2) went back to RWW which has less of an impact on soils (unsuitable capacity and choice of processing technology). The economic and agronomic performances are considerably better.

Public land near **Settat, Morocco** (Project 4) and **Ouagadougou, Burkina Faso** is irrigated with domestic wastewater (and industrial wastewater for Ouagadougou) that is treated via lagooning. In Ouagadougou, treated wastewater also supplies unofficial land where irrigation restrictions do not apply.

In **Korba, Tunisia** (Project 8) and in the NGEST project in the Palestinian Territories, TWW is reused indirectly after pumping from the groundwater.

In **Harare, Zimbabwe** (Project 10), wastewater is treated differently depending on whether it is reused for pasture irrigation (mixed with sludge) or released into the natural environment.

In **Delhi, India** (Project 6), the Okhla plant incorporates many forms of reuse: it supplies wastewater to agricultural users (37 mm3/year), industrial users (58 mm3/year), restores part of the wastewater to the receiving environment and is looking for new uses.

TWWR is integrated in the holistic approach to water management in **Bogota, Colombia** (Project 11). When TWW is diverted for farmers, it means that less water is taken from the river and sufficient flows are maintained for hydroelectric generation downstream.

In **Libya**, several TWWR experiences have been identified, including the **Hadba El Khadra** station (Project 12), where nearly 3,000 ha of crops are irrigated with TWW at the sand filtration outlet.

PART 2

HOW CAN WE CHANGE THE WAY WE ADDRESS AGRICULTURAL WASTEWATER REUSE?

This section provides an analysis of the major components of the sustainability equation for a reuse project (Figure 2). It elaborates on five key questions so as to structure the complementary angles of approach to the eminently complex and multidimensional subject of reuse (Figure 2), as well as to accompany the development of sustainable reuse chains with controlled risks.

The **reuse chain** is defined here as all the **processes and impacts from wastewater production to their final destination after use**. This notion regroups all resource **operators and activities**.

These questions were identified following the capitalization work in Part 1 of the report, discussed with the study monitoring committee, and adjusted or reformulated to better reflect a shared vision of the challenges and prospects for reuse in developing countries. As much as possible, they are developed based on a similar plan starting from an overview to arrive at the prospects and domains to be investigated (Figure 3), and are illustrated by concrete cases and examples on a national or project scale.

FIGURE 3: Logical chapter structure - Ecofilae diagram

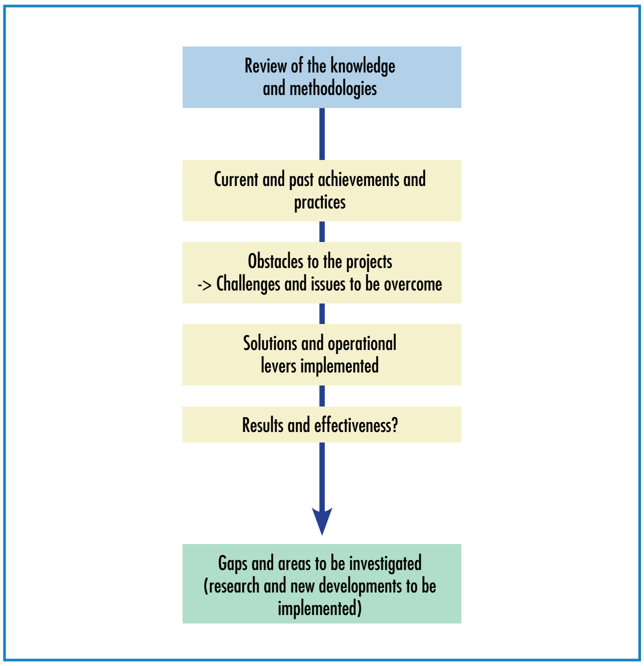
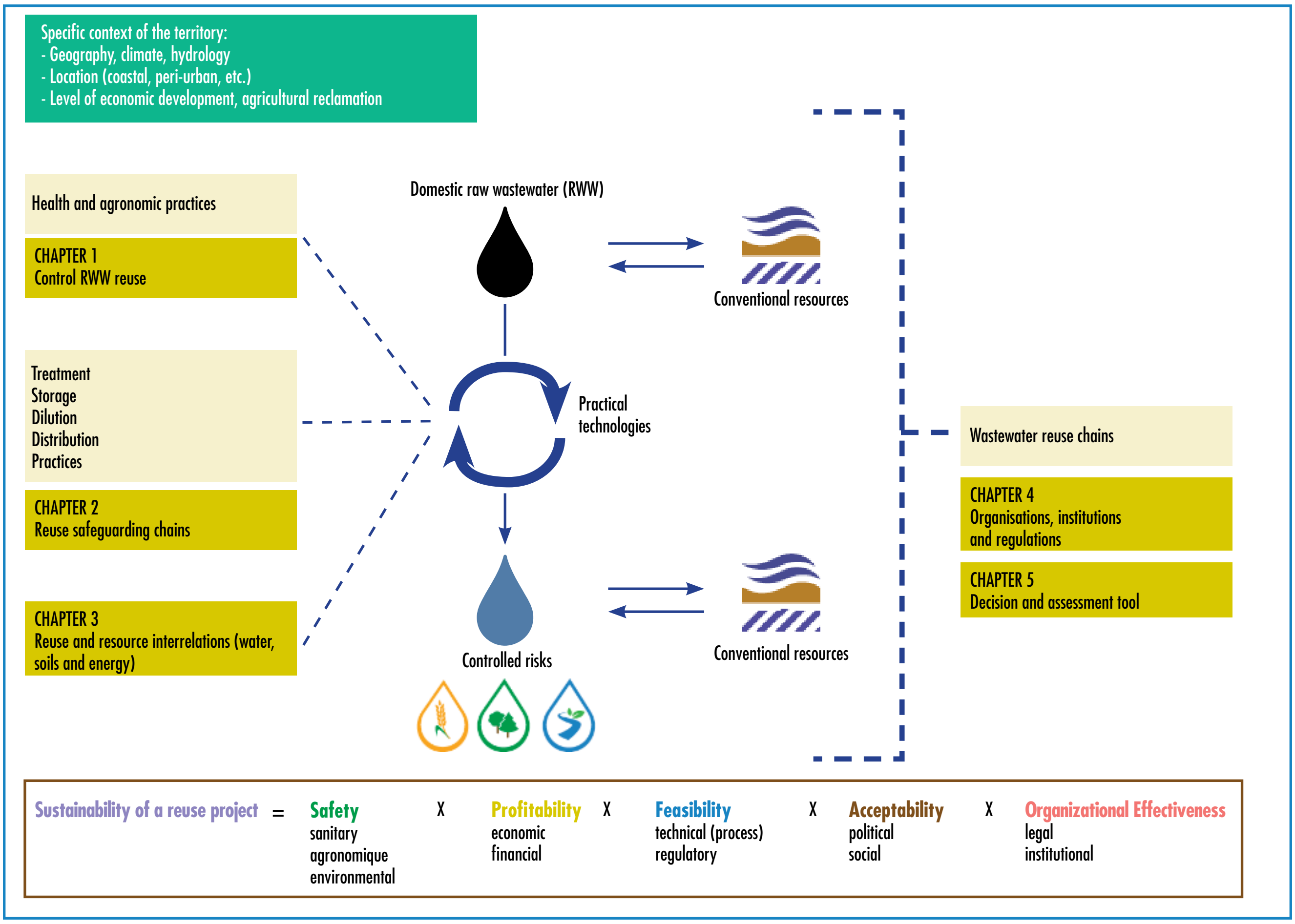


FIGURE 2: The chapters are articulated around the reuse chain concept - Ecofilae diagram



CHAPTER 1

Raw, poorly treated or diluted wastewater reuse : which levers should be used to improve practices?

Whether untreated, poorly treated or mixed with fresh water, **raw wastewater** is still used today, either intentionally or unintentionally, in many parts of the world.

The absence of a wastewater collection, transport and treatment infrastructure in urban areas often results in uncontrolled discharge into drainage and wastewater networks (pipes, artificial canals, natural waterways, etc.). As a result, wastewater may constitute a large part, if not all, of **urban runoff**, especially during the dry season (CGIAR 2012). Farmers can easily access this resource, both within and outside cities. Raw wastewater is **often diluted**, but still contains a high amount of faecal matter. Consequently, the **health risks** are often very high.

Thus, water from polluted streams is probably the most common source of water for vegetable irrigation in urban and peri-urban areas in Africa (Drechsel 2014). In local contexts with limited fertilizers and "safe" water availability, wastewater is perceived as a way to recover the **value of water and the nutrients** it contains, often for free (Scott 2010).

The aim of this chapter is to raise the question of how to **manage the safety** (health, agronomic and environmental) **of RWWR while considering and preserving the benefits that such practices provide** (fertilization, economy, etc.).

This chapter first presents a summary of the current work on wastewater reuse throughout the world (RWWR). It is based on the numerous studies and works carried out by the IWMI in West Africa, particularly in Accra, Ghana (Project 1). The Faisalabad projects in Pakistan (Project 2) and the case of Morocco (Country 2) are also used to illustrate this chapter. Second, the effectiveness of the various levers used by local authorities to control or cope with RWWR and the related health, agronomic and environmental risks is assessed.

The term "**raw wastewater**" (Figure 4), "RWW", will be used for **all water sources with a high faecal content, coming from untreated (raw) wastewater, or wastewater with very low levels of dilution or treatment**. A "low level of dilution or treatment" means the absence of dedicated treatment facilities. However storage, dilution with fresh water, and transport may lead to a potential reduction in pollutants.

RAW WASTEWATER REUSE (RWWR): A COMMON PRACTICE IN DEVELOPING COUNTRIES

In 2012, AQUASTATS reported that 261 millions of hectares of agricultural land have been irrigated worldwide. It has been estimated that approximately **20 million hectares** were irrigated with untreated wastewater (UN, 2003). The surface area of the land irrigated with untreated wastewater is estimated to be 10 times greater than that irrigated with treated wastewater (Scott 2010).
FAO also estimated in 2010 **that 10% of the world's population has consumed crops produced with wastewater**. This figure rises up to 80% in Vietnam.

Figure 5 shows, by country, the areas irrigated with treated wastewater and untreated wastewater. By far, China and India are the countries with the largest area of irrigated land, but they are also the main users of untreated and diluted raw wastewater.

FIGURE 4: Raw wastewater reuse chain - Ecofilae diagram

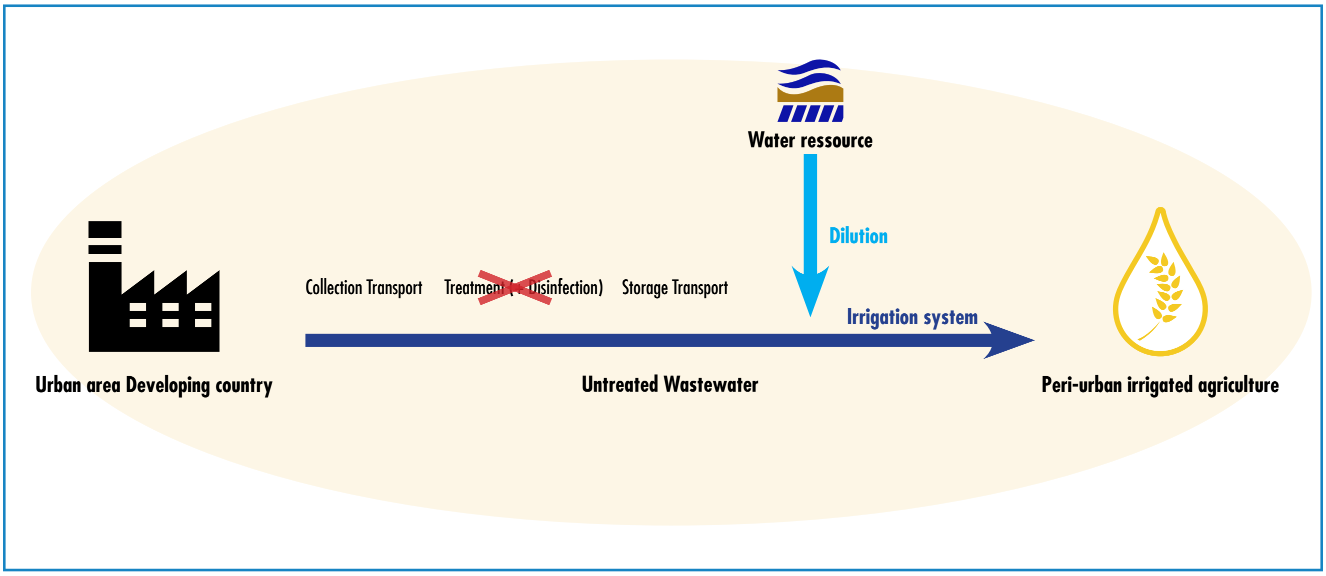
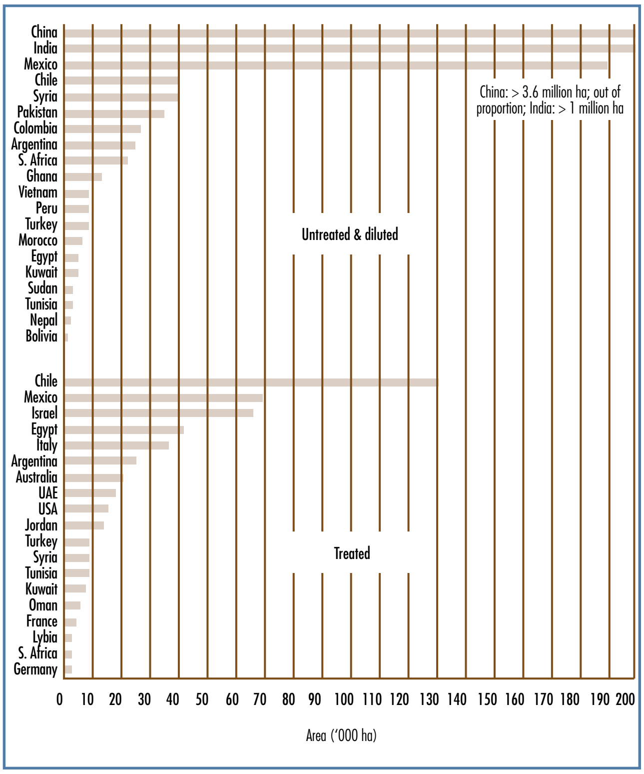


FIGURE 5: Diagram of surface areas irrigated with untreated or diluted water (top) and treated water (bottom) (CGIAR 2012)



RISKS AND BENEFITS LINKED TO THE USE OF RAW WASTEWATER FOR IRRIGATION

Raw wastewater contains chemical pollutants, as well as a wide variety of different **pathogens** that are able to survive for long periods of time in the soil or on the surface of plants, and enter into the food chain. Raw wastewater reuse practices are a source of **risk to public health, the environment and agronomic systems** (soils and plants).

RWW is also a source of **fertilizers** (nitrogen, phosphorus and organic matter).

Health challenges related to the presence of pathogens

Whether via **direct contact** (skin or ingestion) with water and aerosols from spraying, or indirectly through the **consumption of agricultural products**, raw wastewater is a major source of sanitary contamination. In fact, it contains various viruses, parasites, bacteria, etc.

Reuse practices have been and continue to be a leading cause of diarrhoea, cholera, typhoid, and shigellosis epidemics in Africa and Asia, with many hospitalized patients and many deaths (WHO 2006). They are also a likely contributor to parasitic and skin infections.

Farmers and their families, people living near irrigation sites using wastewater, and particularly consumers are affected (USEPA 2012).

Health and environmental challenges linked to chemical components and heavy metals in industrial wastewater

Raw wastewater in peri-urban areas not only comes from a domestic origin, but it may be mixed with **industrial wastewater** (Project 5 and Project 6) and, as a result, there is a wide range of quality. Raw wastewater is then a source of health and environmental contamination (water, soils and plants).

The **2006 WHO guidelines** provide the maximum tolerable concentrations of various toxic chemicals in soils. They were established by assessing human exposure through the food chain. These WHO guidelines do not specifically address how to reduce chemical contaminants in wastewater for reuse in irrigation. However, the solution must be sought at the level of the specific sources of pollution (often industrial).

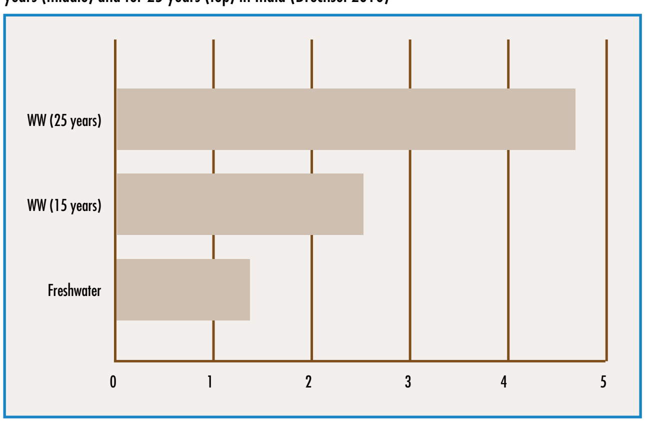
In the **Settat region of Morocco** (Project 4), prior to the implementation of the treated wastewater reuse project, studies assessed the lead load and prevalence of Giardia intestinalis in untreated wastewater (El Kettani et al. 2010). The results of the health studies highlighted: (1) the absence of lead-related impacts (diseases, abnormal loads, etc.), and (2) a higher prevalence of Giardia intestinalis in populations using and working in contact with raw wastewater.

The agronomic added value of raw wastewater

Farmers on the outskirts of cities find a **nutrient-rich** resource in raw wastewater: **nitrogen, phosphorus, organic matter**. Relatively intensive and diversified agriculture is being developed, land requirements are being reduced, and through an optimal use of water and nutrients, farmers are reducing their consumption. For many farmers, raw wastewater is the only source of fertilization. The cases of Accra, Ghana and Faisalabad, Pakistan illustrate this (Project 1 and Project 2).

The presence of organic matter can have positive or negative effects on soils depending on the nature of the organic matter. IWMI's work (Drechsel 2010) found that "organic matter added through wastewater improves soil structure, acts as a storehouse of essential nutrients for crop growth and improves the charge characteristics of irrigated soils, such as cation exchange capacity (CEC)". Studies in India on the long-term effects of irrigation using wastewater on the physical properties of soil reveal an increase in aggregate stability, retention capacity, hydraulic conductivity and total porosity. In addition to beneficial effects on organic matter and soil physical parameters, the organic carbon content of soils irrigated with wastewater increases, regardless of the soils and agro-climatic conditions (Figure 6).

FIGURE 6: Carbon dynamics in soil irrigated with fresh water (bottom) water, raw wastewater for 15 years (middle) and for 25 years (top) in India (Drechsel 2010)



WHY IS RAW WASTEWATER REUSE SO WIDESPREAD?

The construction and use of efficient reclamation infrastructures are difficult to implement

The WHO's approach (2006 Guidelines) recognizes that conventional wastewater treatment is not always feasible, particularly in resource-constrained countries. Reclamation infrastructures (collection, transport and treatment), upstream from the reuse chain, cannot always be implemented for various reasons (**lack of capacity, organizational or financial reasons**) and, when they are built, they often do not work efficiently. The urban population explosion, in many cases, far surpasses the capacity of rapidly overburdened infrastructures (e.g. Beit Lahia WWTP in Palestine - Project 9).

In these cases, alternative strategies to mitigate the risks associated with RWWR need to be assessed and applied to start the transition toward planned, controlled and secure systems.

Raw wastewater provides livelihoods for many people living in and around cities

Agricultural RWWR is often **officially banned** but is widely practised and unofficially tolerated.

In fact, **a whole urban and peri-urban economy** is based on peri-urban agriculture and therefore on wastewater reuse, in places where other water resources are not available (treated wastewater, surface and groundwater) (CGIAR 2012) and where no other suitable alternative is proposed. The entire food chain is dependent and affected, from the farmer who accesses a water resource that is often free, to the consumer, via small retailers. It is therefore essential to maintain these chains in order to maintain jobs and incomes and to improve diets (diversified vegetables and fruits) and general food safety.

HOW CAN WE ADDRESS THIS RAW WASTEWATER REUSE?

Bans, an ineffective means

Governments and bodies responsible for enforcing a law prohibiting RWWR are often **surpassed by practices** they cannot or do not want to control because they are aware of their economic importance.

This often results in uncontrolled practices, making it very difficult for authorities to implement measures to limit risks, since these practices are not part of the debate given that they are officially prohibited.

To effectively eliminate RWWR by prohibiting it, countries must be able to provide farmers with safer, more profitable and more sustainable alternatives. Morocco has embarked on this path: large volumes of raw wastewater are still used in irrigation (70 mm^3), but many projects at water treatment plants include the benefits of treated wastewater (Country 2 and Project 4).

Dilution, a solution that can be controlled

RWW in urban environments is often discharged and recovered in drainage channels or waterways where it mixes with stream water and storm water. If there is a fairly high amount of dilution (strong seasonal variation depending on the region), the risks can be reduced, and reuse is then done indirectly. However, RWWR and the resulting dilution must be controlled. CGIAR even estimates that in some countries, a low-cost treatment of domestic wastewater can result in lower quality water than untreated wastewater diluted in channels or streams (CGIAR 2012).

In **Egypt** (Country 4), untreated domestic wastewater is often discharged into the Nile, its delta or into drainage channels. This practice is responsible for high levels of bacterial contamination. Mixed and diluted with fresh water, they are reused downstream for irrigation (rice, wheat, etc.) or aquaculture. Part of this water is sometimes treated naturally by crossing wetlands prior to reuse (e.g. Lake Manzala).

Promoting good practices to reduce risks at different levels: the WHO's 2006 multi-barrier approach

The **WHO's multi-barrier approach** comes from the conclusion that conventional reuse (with treated wastewater) is impossible in low-income countries where a small percentage of the wastewater produced is actually treated. **Measures, other than prior treatment, to reduce the risks associated with RWWR exist**. In this way, risks can be controlled and the reuse can be coordinated. In some cases, these measures should be promoted and implemented by management and control bodies (CGIAR 2012).

The WHO's recommendations (2006) for raw wastewater target locally feasible alternatives through a set of measures to reduce the risk of contamination, **at any point in the chain between wastewater production and the consumption of contaminated food**. However, among the efforts being made on wastewater management, treatment is still the primary measure to reduce the health risk.

This risk assessment framework identifies and distinguishes vulnerable communities (agricultural workers, members of communities where agriculture is irrigated with wastewater, and consumers) and considers trade-offs between potential risks and nutritional benefits (CGIAR 2012).

The **Thanh Tri District in Hanoi, Vietnam** is a good example of the effectiveness of implementing **a multi-barrier approach**: aerated wetlands have been built to minimally treat raw wastewater. This water is then used by farmers who implement appropriate practices (the wearing of gloves and boots) and by consumers. Crop rotations have also been adapted to the water quality, transitioning from rice cultivation to aquaculture and the production of aquatic vegetables.

Gradual transition

Toward planned and controlled TWWR

Wastewater treatment remains the primary factor that reduces the risk of contamination in the wastewater reuse chain. **Moving towards planned, controlled, centralized or decentralized reuse is still thought to be the safest solution**

The WHO's multi-barrier approach

The aim of this specific approach is to:

- define the maximum tolerable additional disease burden;
- derive tolerable disease and infection risks;
- determine the required minimum pathogen reduction targets so as to ensure that the tolerable disease and infection risks are not exceeded;
- determine how required pathogen reduction can be achieved;
- implement a verification monitoring system.

The figure and table below present an overview of the health protection measures that are part of, on the side lines or are done after treatment along the agricultural wastewater reuse chain. An overall reduction of the risks is best achieved when these measures are combined, i.e. in a multi-barrier approach. Awareness campaigns on the invisible risk of pathogens must go hand-in-hand with the promotion of these practices.

This step-by-step approach provides local managers with flexibility to manage the risks of irrigation with wastewater, providing them with locally viable and combinable options, unlike the use of a quality level threshold approach as the only regulatory option.

On-farm and off-farm risk mitigation measures are generally cheaper and more cost-effective than conventional wastewater treatment and therefore suitable for resource-poor settings. However, safety measures requiring an on-farm infrastructure may require land tenure which many urban farmers do not have. The most effective health protection recommendation is to ensure that the crops produced are not consumed raw. However, this option requires a suitable monitoring capability and viable crop alternatives for farmers (CGIAR 2012).

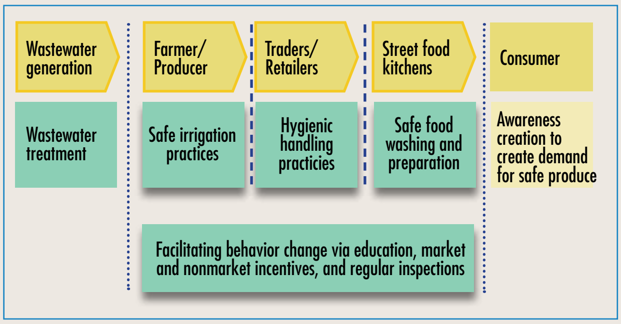


FIGURE 7: The multi-barrier approach for public health when wastewater treatment is restricted – WHO 2006

Whenever possible, the following measures help mitigate the risk of contamination:

- do not irrigate food crops that are consumed raw;
- install on-farm storage and processing systems;
- convert to local irrigation;
- wear protective clothing and gloves (farmers);
- wash, store and cook products before consuming them;

These measures are repeated and explained in more detail in the table below.

TABLE 2: Non-conventional control and health protection measures and associated reduction of pathogens – WHO 2006

CONTROL MEASURE	PATHOGEN REDUCTION (log units)	NOTES
A.Wastewater treatment	6-7	Reduction of pathogens depends on type and degree of treatment selected.
B. On-farm options		
Crop restriction (i.e., no food crops eaten uncooked)	6-7	Depends on (a) effectiveness of local enforcement of crop restriction, and (b) comparative profit margin of the alternative crop(s).
On-farm water treatment:		
(a) Three-tank system	1-2	One pond is being filled by the farmer, one is settling and the settled water from the third is being used for irrigation.
(b) Simple sedimentation	0.5-1	Sedimentation for ~18 hours.
(c) Simple filtration	1-3	Value depends on filtration system used.
Method of wastewater application:		
(a) Furrow irrigation	1-2	Crop density and yield may be reduced.
(b) Low-cost drip irrigation	2-4	Reduction of 2 log units for low-growing crops, and reduction of 4-log units for high-growing crops.
(c) Reduction of splashing	1-2	Farmers trained to reduce splashing when watering cans used (splashing adds contaminated soil particles on to crop sufaces which can be minimized).
Pathogen die-off (cessation)	0.5-2 per day	Die-off between last irrigation and harvest (value depends on climate, crop type. etc).
c. Post-harvest options at local markets		
Overnight storage in baskets	0.5-1	Selling produce after overnight storage in baskets (rather than overnight storage in sacks or selling fresh produce without overnight storage).
Produce preparation prior to sale	1-2	a) Washing salad crops, vegetables and fruits with clean water.
	2-3	(b) Washing salad crops, vegetables and fruits with running tap water.
	1-3	(c) Removing the outer leaves on cabbages, lettuce, etc.
D. In-kitchen produce-preparation options		
Produce disinfection	2-3	Washing salad crops, vegetables and fruits with an appropriate disinfectant solution and rinsing with clean water.
Produce peeling	2	Fruits, root crops.
Produce cooking	5-7	Option depends on local diet and preference for cooked food.

Sources : Amoah et al. (2011).

for attaining the highest level of sanitation possible. When operational and financial capacities improve, a changeover becomes necessary, while establishing regulatory and monitoring protocols. The process may be spread out over many years depending on the country level (CGIAR 2012).

PROSPECTIVES FOR FUTURE DEVELOPMENTS

The health risk, defined by the threat (water quality in terms of contaminants) and vulnerability (human exposure) encountered, is too high in the case of uncontrolled and unmonitored raw wastewater reuse. The economic and agronomic benefits that it provides cannot offset these risks: **controlled and monitored systems are key**.

As explained above, treatment is the main measure limiting risks in the reuse chain, however it should not be considered as a unique and sufficient solution. There are other barriers that are cheaper and easier to implement that reduce contaminants (threat), such as wastewater storage, or barriers that reduce exposure (vulnerability). Moreover, treatment systems reduce the pathogen burden, but also greatly reduce organic matter and nutrient concentrations.

As a result, research on treatment technologies (even low-cost technologies and for decentralized systems) should concentrate on systems that can reduce the **pathogen burden while maintaining the agronomic potential of wastewater**. The reduction of risks (pathogens and other pollutants) related to the agronomic system (soils and crops), as well as transport, storage and irrigation systems, must be better understood and characterized. The most cost-effective solutions should be considered.

Are the basic steps of treatment (storage, wetlands, etc.), to which exposure mitigation measures are added, enough to control the health risk? More assessments of these types of projects are needed and new pilot projects should be implemented.

Egypt - Agricultural pumping from the Nile Delta © Condom, 2015

CHAPTER 2

Which treatment chains are suitable for safeguarding wastewater reuse projects?

The **wastewater reuse chain** (Figure 8) consists of a sequence of steps and processes that are involved starting from the production of raw wastewater up to the end use of this water on irrigated crops, including technological aspects (raw wastewater collection and transport network, treatment technologies, storage and distribution systems, irrigation techniques), as well as implemented practices (agronomic and environmental management practices).

In developing countries, wastewater treatment systems were originally built and designed with health and environmental protection objectives in mind. Until recently, TWWR was rarely taken into account. The interests and motivations for the construction of a wastewater treatment plant can now be strengthened by the expectation of reusing treated wastewater, particularly for irrigation, thereby giving it economic value (Barcelo 2010).

This chapter focuses on the **treatment processes that have been implemented and adapted to developing countries** (middle and low-income countries) **for treated wastewater reuse**. Different options in terms of treatment techniques exist, and there is a wide range of reuse chains from minimally treated water up to high-tech chains (Figure 9). Experience feedback (**Country summaries** and **Project summaries**) shows the various chains in diagram form, from the source of the wastewater to its use in agriculture, and make it possible to discuss the pertinence of the technical choices (when available in the literature), in particular treatment, with regard to specific local contexts.

The term "**treated wastewater**", "**TWW**", will be used here **for all sources of urban, industrial or agricultural wastewater that have undergone various levels of extensive treatment in order to make the water safe and to limit the risks associated with their reuse**.

WHAT ARE THE TREATMENT-RELATED PROBLEMS IN WASTEWATER REUSE PROJECTS?

In developing countries, especially in the Mediterranean region, the major obstacles to the sustainable reuse of wastewater in terms of treatment are:

- the **malfunction** of the implemented technologies;
- a **lack of efficiency** in the treatment process to achieve the water quality required for reuse;
- a **loss of control in the quality of the water throughout the entire process**, from when it enters into the treatment system to its final use.

The malfunction of the treatment process is a major obstacle. Water treatment plants often do not function properly due to a lack of resources, spare parts for maintenance, staff incentives and/or skills, or because the plant is overloaded or underloaded.

In addition to organizational or design reasons, **even the selection of treatment technology** may be called into question. In conditions where **energy and capacities are restricted**, developing countries should focus on **low-cost, low-tech and low-energy technologies**.

In some countries, the set of technologies proposed to engineers and policy makers is often limited to a narrow range promoted by institutional organizations: e.g. activated sludge, biotrickling filters or lagoon systems (in Morocco). Authorities often lack information and technical skills for the wide range of existing technologies (Barcelo 2010).

In Faisalabad, Pakistan (Project 2), the choice of the lagoon system and their capacity may explain the low TWW quality.

FIGURE 8: Treated wastewater reuse chain - Ecofilae diagram

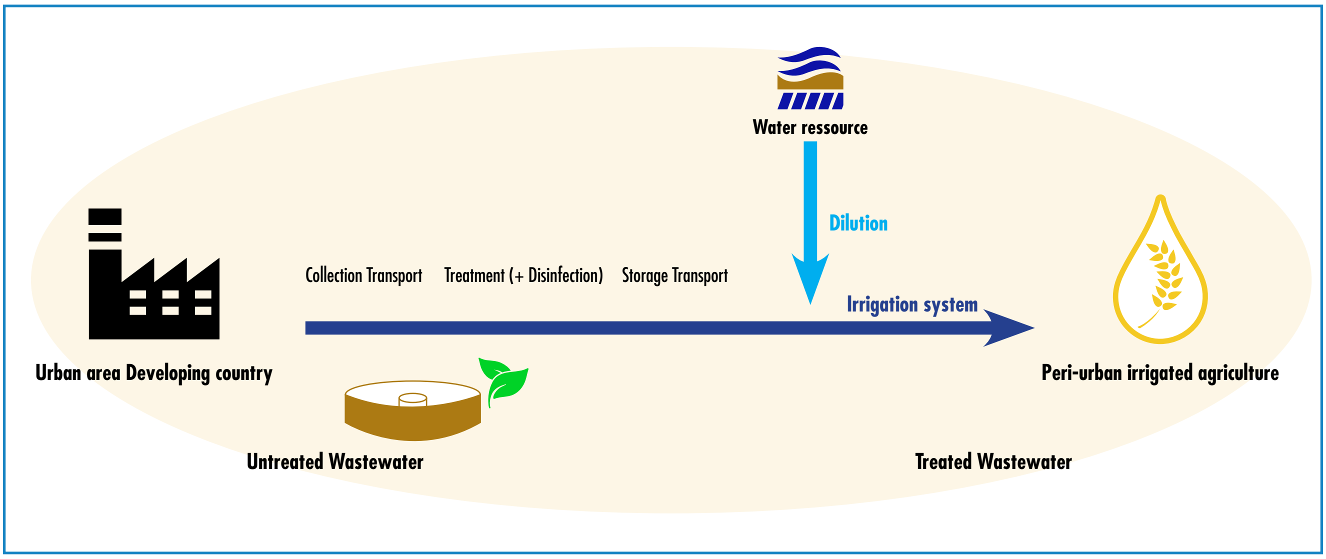
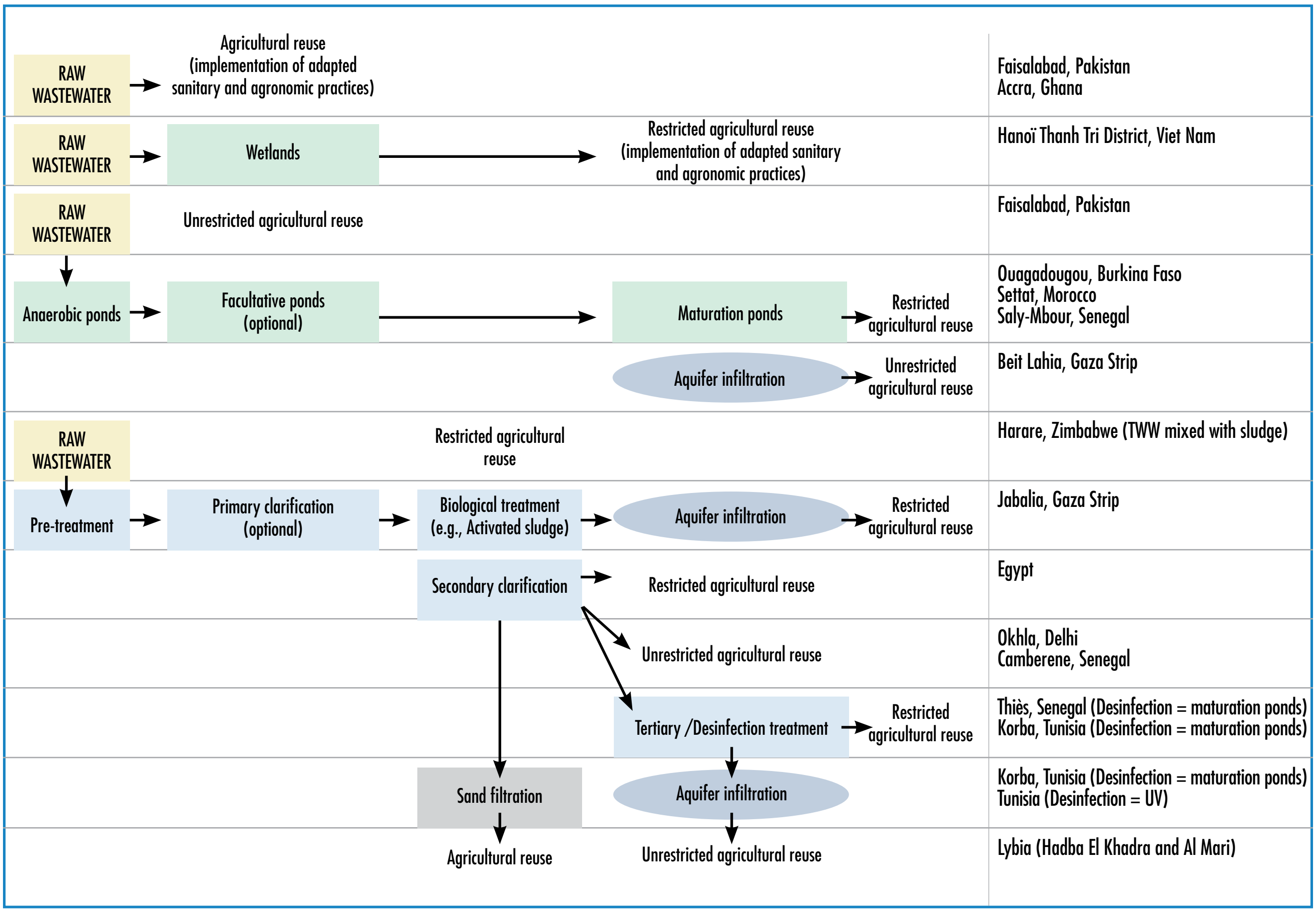


FIGURE 9: Treatment solutions implemented in certain developing countries - Ecofilae diagram



HOW TO CHOOSE THE TREATMENT PROCESS BEST SUITED TO ITS CONTEXT?

It is not an easy process to choose the best technology available: it requires a technical assessment and comparisons (bottom-up approach, from its use to the selection of the source and treatment). It must be well thought out based on well-established criteria including:

- The possibilities for reuse (is there really a demand for treated wastewater?);
- The availability and cost of land (if land is inexpensive, then anaerobic lagoons are an option);
- The required quality of the outgoing effluent (depending on local regulations, types of irrigated crops, sanitary and agronomic practices in the production chain);
- The size of the community (large or medium urban area, rural area);
- The quality of the incoming wastewater (from a domestic origin only? at what concentration? dilution with rainwater? industrial waste?);
- The location of the wastewater treatment plant (near irrigated areas? in an area with a high environmental risk?);
- The economic and technical conditions (will the project be technically and economically sustainable over time?).

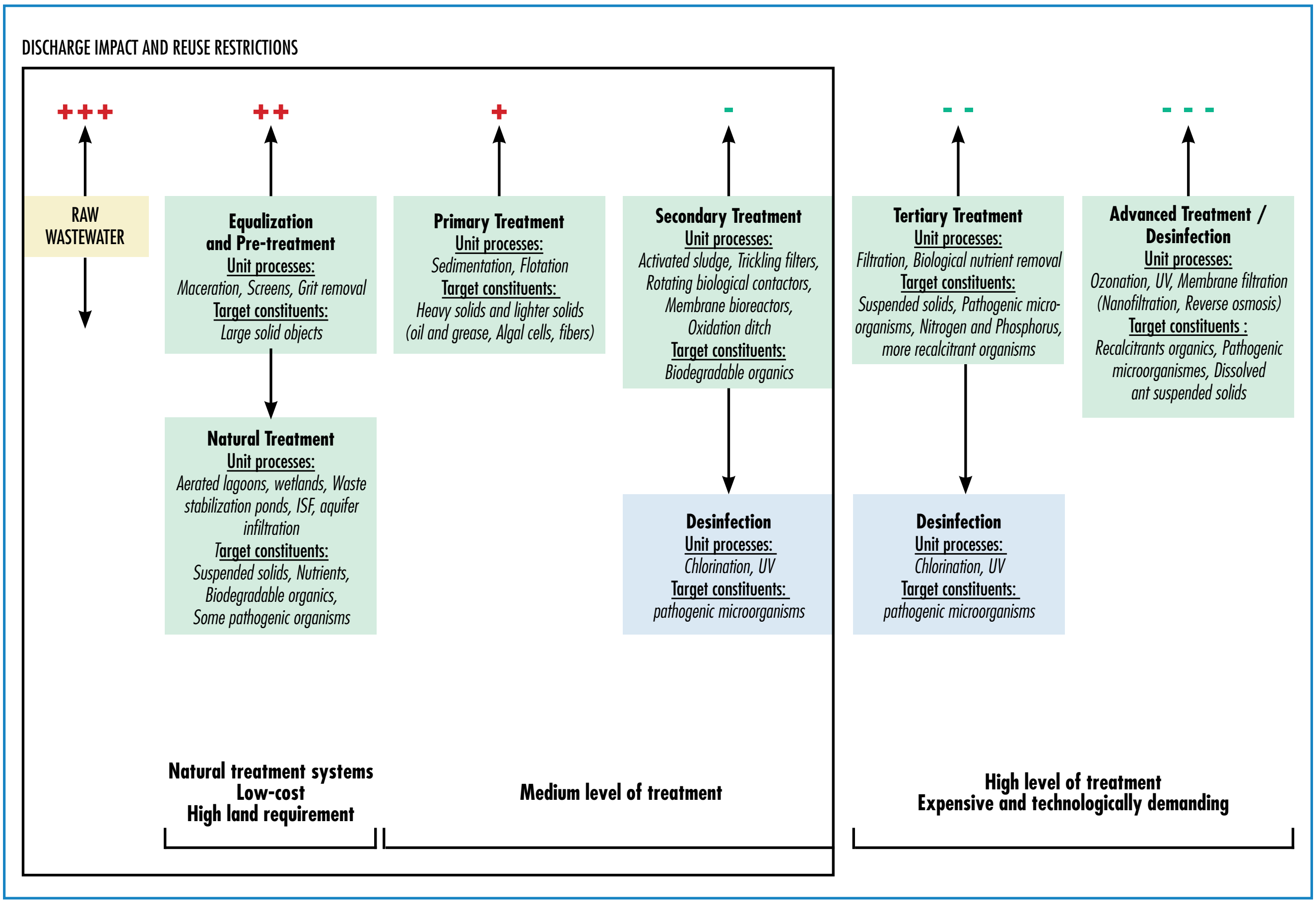
Urban and rural communities in the areas involved in this study have several characteristics in common, which guide the design and selection of treatment technologies (Barcelo 2010):

- the need for seasonal wastewater storage prior to the irrigation season (wastewater is produced continuously, the demand for irrigation water is periodic and seasonal);
- in general, there is enough low-cost land near urban communities;
- there is usually abundant sunshine in these areas, which gives an advantage to photosynthetic processes or other processes dependent on solar energy;
- the wastewater is relatively concentrated due to the low per capita consumption of water;
- wastewater has a relatively high level of pathogenicity due to the endemicity of certain diseases and the strong presence of vectors;
- lack of capital;
- the absence, scarcity or lack of unreliable electric power supply service;
- the need for minimal, simple and inexpensive operation and maintenance installations.

WHAT ARE THE AVAILABLE TREATMENT TECHNOLOGIES?

Wastewater treatment generally consists of a series of physical, chemical, biological unit processes that can each specifically eliminate wastewater components (Figure 10). Thus, various combinations of unit processes are possible (Sanghi 2013). The standard treatment technologies are primarily oriented towards organic and hygiene parameters.

FIGURE 10: Wastewater treatment processes for their reuse - Ecofilae diagram & adapted from Sharma and Sanghi, 2013



Given that the benefits of pollutants such as nitrogen and phosphorus increase through irrigation, there is no need to have a high reduction efficiency (Barcelo 2010). Usually wastewater does not contain heavy metals (unless domestic wastewater is mixed with industrial effluents), which means that the main concern with regards to health risks is pathogens. Wastewater salinity is also a major concern for environmental and agronomic risks (Choukr'Allah 2010).

Pre-treatment

Pre-treatment is an essential step upstream of any treatment system (screening, sandblasting, sieving and removal of grease). It consists of removing all material that may be easily recovered from raw wastewater (garbage, leaves, branches, gravel, sand and other large objects) before they damage the pumps or the subsequent treatment lines.

In **Faisalabad, Pakistan** (Project 2), grids, which were not initially installed in the wastewater inlet channel, have limited the proliferation of plants and mosquitoes.

High-tech and high-cost treatment technologies

The treatment options below (primary and secondary treatments) are often more suitable for the removal of environmental pollutants than for pathogens.

Many of these processes can also be difficult and costly to use in developing countries.

The **primary treatment** allows the sedimentation of heavy solids via gravity or the suspension of light solids. Chemical coagulants and flocculants may be used prior to sedimentation/flotation to improve the solid-liquid separation. The primary treatment is generally insufficient to remove viruses, bacteria and metals (Sanghi 2013).

When primary effluents are used for crop irrigation or for aquaculture, additional protective measures are needed: restrict irrigated crops, use personal protective equipment, wash and cook food, regularly monitor chemical and toxic accumulations in soils and food products.

The **secondary treatment** consists of a combination of biological treatments and clarifications. There are a wide variety of procedures, including (Valentina Lazarova 2004):

- activated sludge systems; in developed countries, this intermediate stage is followed by other complementary treatment processes;
- biotrickling filters; easy to use and inexpensive, this process has a limited treatment efficiency and a high dependence on carbon and hydraulic loads, and is highly temperature sensitive. These latter characteristics are very limiting for the implementation of such systems in developing countries.

When the secondary treatment is combined with adequate disinfection, secondary-treated wastewater may be considered safe for the irrigation of crops. However, there are certain restrictions when treated wastewater is applied with sprinkler irrigation systems or when irrigating crops for which the products do not undergo processing (Sanghi 2013).

In **Harare, Zimbabwe** (Project 10), a dedicated trickling filter is used in conjunction with an activated sludge process to treat reused treated wastewater for the irrigation of fodder crops. Reused treated wastewater is mixed with sludge from both processes. A mixture containing 3 to 4% solid matter is obtained.

Activated sludge systems are often expensive. It is difficult to recover the operating and maintenance costs thereby constituting the main obstacles to the implementation of these high-technology processing systems in developing countries (Kampa 2010).

The elimination of primary and secondary sludge is also necessary to prevent the spread of pathogens and other contaminants into the soil and streams (Sanghi 2013). Sludge management may become problematic (Country 3).
Disinfection can be carried out after secondary treatment using free chlorine, either in the form of chlorine gas or sodium hypochlorite or calcium. The effectiveness of chlorine with respect to bacterial inactivation is well known. Chlorine is also relatively effective against viruses (up to 3-log reduction), but it is less effective against helminth eggs (less than 1-log reduction).

In addition to free chlorine, chlorine dioxide and UV are also used as primary disinfectants for wastewater treatment and for agricultural reuse. They are generally more effective at inactivating viruses and protozoa than free chlorine. Chloramine, a less powerful disinfectant, is used in a second stage in the purified water distribution system (Sanghi 2013).

For economic reasons, the combination of chlorine and UV is widely used in wastewater reuse projects in developed countries, but more rarely in developing countries (Asano 2008).

The elimination of organic pollutants in treatment processes is necessary in the wastewater reuse chain so as to reduce the potential for the secondary proliferation of pathogens in distribution systems and to ensure effective disinfection (Valentina Lazarova 2004).

Low-tech and low-cost treatment technologies

Extensive natural treatment technologies, also known as **low-tech** treatment systems, can be used in subtropical areas where dry seasons and wet seasons alternate and mean temperatures are above 20°C (Valentina Lazarova 2004). By using sedimentation, biological degradation, and natural disinfection (soil or UV) processes, they are generally quite efficient, reliable in terms of their treatment performance, affordable with regards to their construction and have less stringent requirements in terms of energy and maintenance (Sanghi 2013).

Lagoon systems

Lagoon systems form a series of interconnected shallow lagoons. They are designed to use natural processes of **biodegradation, disinfection** by sunlight, and particle **sedimentation** via gravity, to purify water. Very high loading rates can be applied (10 to 20 times higher than in conventional activated sludge treatments) (Choukr'Allah 2010).

The operating principle is based on the degradation of organic matter by bacteria and the photosynthesis of algae (Figure 11).

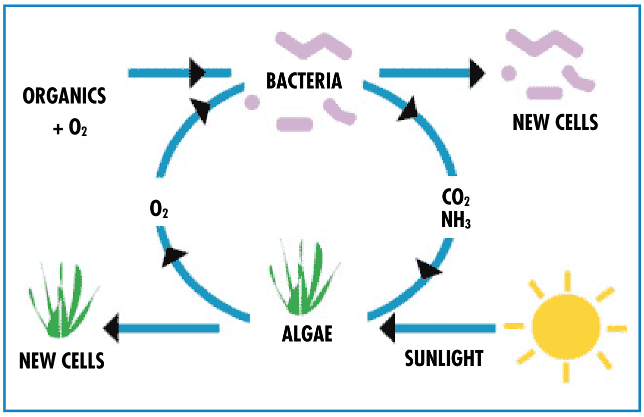


FIGURE 11: Natural mechanisms implemented during lagooning - UNEP

When properly designed and operated, they are highly effective at eliminating pathogens and can be operated at low cost. Pathogens are gradually removed along the series of lagoons, the maximum removal takes place in the maturation pond (the last lagoon in the series). However, lagoons must be designed, operated and maintained so as to prevent the reproduction of disease vectors in lagoons.

However, they lose their comparative economic advantages over mechanized treatment systems when the price of land is high.

Wastewater treatment project via lagooning for agricultural reuse in Tizi n'Oucheg (High Atlas - Marocco) - Mediaventures

Different types of lagoons can be used in a series or in parallel (Valentina Lazarova 2004) & (Choukr'Allah 2010)
- anaerobic ponds are used as a pre-treatment stage (deep ponds with a long residence time);
- facultative lagoons (or oxidation ponds) are used for to remove carbon (near-bottom anaerobic conditions and aerobic conditions at the surface);
- lagoons aerated via floating mechanical aerators remove carbon at higher rates than facultative ponds. They are often used in high-income countries (France) and more rarely in low-income countries (but they do exist in Morocco);
- maturation ponds are relatively shallow systems that are used as a disinfection step. They are often used in water reuse chains in combination with other lagoons in series, or in intensive biological treatment systems (Tunisia and Morocco). This technology effectively removes helminth

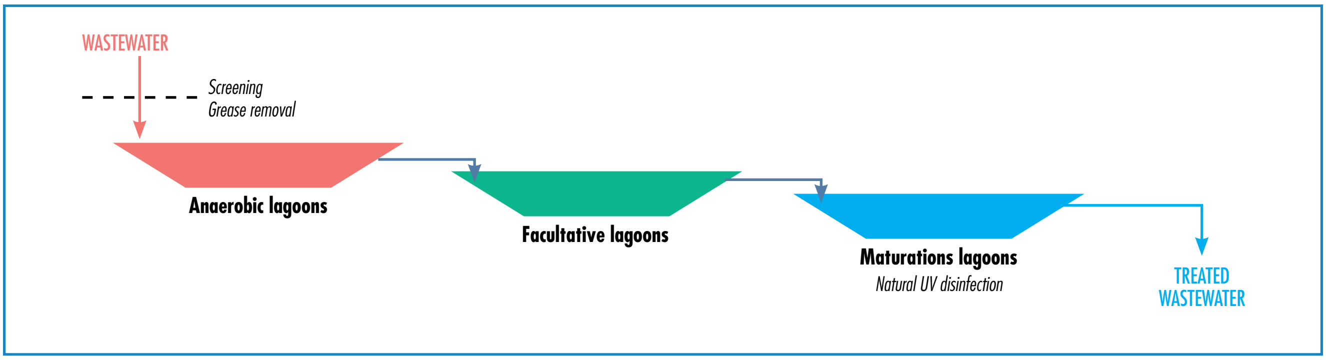


FIGURE 12: Schematic example of the lagoon treatment chain - Ecofilae diagram

eggs and ensures wastewater disinfection via the direct action of light (UV). However, in the case of unrestricted irrigation, the performances may be insufficient. These ponds can also act as storage tanks.

Anaerobic conditions lead to controlled conversions of organic pollutants into carbon dioxide and methane, which can be used as an energy source (not illustrated in this study).

Lagooning is currently considered as the preferred method for wastewater treatment in hot regions (Middle East, Africa, and Asia). This technology is recommended in Morocco (Country 2) and Tunisia for cities with between 2,000 and 5,000 inhabitants.

The major disadvantages of these lagoon systems are:

- a certain degree of rigidity in the exploitation, particularly in terms of flow rates, and seasonal variations (risk of overloading);
- Sensitivity to evaporation, particularly for dry and windy areas (Project 2);
- Sensitivity to water turbidity provoked by plant and algal growth;
- The limited effectiveness of the system with regard to toxic materials (domestic or industrial).

In the dry season in **Nairobi, Kenya**, one of Africa's largest lagoon treatment systems treats a flow rate of 80,000 m^3/day (maximum capacity 240,000 m^3/day).

The treatment comprises 8 sets of parallel ponds, including a primary facultative lagoon followed by a sequence of 3 maturation lagoons. The quality of the effluent is in line with the WHO's guidelines for unrestricted irrigation.

Artificial wetlands

The aim of artificial wetlands (Choukr'Allah 2010) (Sanghi 2013) is to imitate the properties of natural wetlands in a monitored and controlled environment. The system uses natural processes involving the vegetation, soil and associated microbial assemblages to purify the wastewater.

They are effective in lowering the biological oxygen demand (BOD), suspended solids (SS) and nitrogen. They have minimal operating (low energy consumption) and maintenance requirements.

There are two types of artificial wetlands (Figure 13):

- "Subsurface Flow System" (SFS) type wetlands, where water flows beneath the surface. They are lined with ditches that have been filled with gravel, sand or soil substrates and planted with suitable plant varieties. Treatment is effective when wastewater is in contact with plant roots, soil or the substrate. Reeds are commonly used;
- "Free Water Surface" (FWS) type wetlands, where water flows on the surface. These are shallow channels or open surface ponds with emerging vegetation. The two commonly used floating aquatic macrophytes are water hyacinth and duckweed. The shallow depth, low flow velocity, and presence of plant stems and litter regulate water flow. The treatment is effective when the flow of water slowly passes between the stems and roots of the plants.

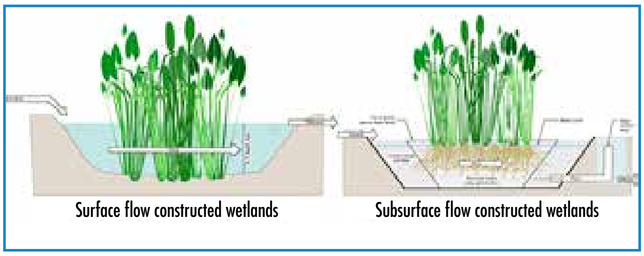


FIGURE 13: Two artificial wetland systems to purify wastewater - Ecofilae diagram

Artificial wetlands may also be implemented in addition to other treatments. They can be combined with other low-tech treatment units, or can be used as a tertiary treatment after activated sludge or lagooning.

The spread of this technology in developing countries is a slow process, despite favourable climatic conditions. Systems adapted to the characteristics of tropical and subtropical areas have yet to be designed. However, this method has been tested and implemented in the village of Kothapally in India (Telengana) (ICID 2015) on FWS systems in order to identify efficient plants and to assess treatment performances. TWW is used to irrigate 1 ha of crops.

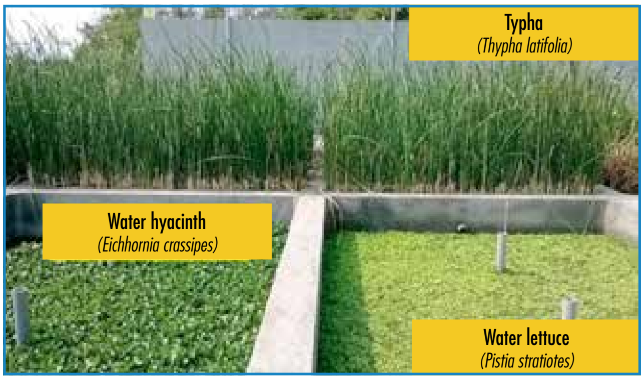


FIGURE 14: FWS tested in the village of Kothapally (India) – Data et al. (2015) ICID 2015

Intermittent sand filters

Intermittent sand filters have long been used in the Mediterranean region as a low-cost, low-energy wastewater treatment process. This technology is often used as a tertiary stage or disinfection step, after conventional treatment (anaerobic ponds).

Intermittent sand filter systems contain beds of granular material, or sand, drained from underneath (infiltration and percolation). This aerobic system is based on the principle of flooding and drying cycles in infiltration ponds. They retain high rates of viruses and helminth eggs. The level of disinfection of secondary effluents depends mainly on the level of saturation and the rates of hydraulic conductivity (Choukr'Allah 2010).

This system is recommended for small stations as tertiary treatment or disinfection. It requires less space than maturation lagoons or a Soil Aquifer Treatment (SAT). This technique is simple in terms of use and demands low investment and operating costs (Valentina Lazarova 2004).

These treatment processes have been implemented in Libya (Project 12).

Soil Aquifer Treatment

Unlike a direct injection into the aquifer, **Soil Aquifer Treatment** (SAT) uses a surface infiltration basin that can ensure the treatment of poor quality effluents, and avoids the microbial contamination of groundwater.

The effluent is pumped into a basin which alternates water introduction and water removal. Wastewater infiltrates through a clogged layer at the surface and then an unsaturated zone before reaching the aquifer (saturated zone) (Valentina Lazarova 2004).

The effectiveness of this system varies considerably depending on the type of soil and loading rate. The hydraulic retention time varies from several months to one year. The reclaimed water can then be used for unrestricted irrigation.

This process is implemented at the end of treatment in Korba, Tunisia (Project 8) and in the NGEST project in the Gaza Strip (Project 9).

Storage

Storage is an essential and important step to **equalize the peaks and fill the low periods**, since the demand for irrigation water varies over time and is primarily during the dry season, whereas the supply of wastewater is globally continuous over time (Asano 2008).

In **Tunisia**, one of the main obstacles for TWWR was the need to set up storage systems to buffer the time lag between the demand for irrigation water and the availability of treated wastewater (Asano 2008).

There are two types of storage:

- **short-term storage** (residence time in the order of several days to several weeks). These are open- or closed-pond systems. They are used for small irrigated areas and for small volumes. Residual chlorination often needs to be applied between the storage and distribution;
- **long-term storage** (seasonal storage during the wet season to provide for a high demand for irrigation in the dry season). Surface storage reservoirs can be set up. Long-term storage can also be carried out in aquifers, to ensure a reliable water supply and to improve water quality. In this case, groundwater contamination must be limited and controlled.

Maturation lagoons used as a disinfection step may also be used to store treated wastewater.

Storage and distribution systems must take the often underestimated changes in water quality into account. Water quality may be degraded or improved due to the effects of storage and the distribution between the source of production and the points of use. These two steps must therefore be considered as potential recontamination or abatement processes and must be anticipated when sizing treatment systems (Valentina Lazarova 2004). The mechanisms that impact water quality in storage tanks are similar to those involved in lagoon systems. Deep tanks with a small surface area are recommended (economic reasons), however more pollutants can be removed in the upper water layer where temperatures are higher. If it is not possible to use chlorination after storage, it is then necessary to rinse the entire distribution system and the irrigation network prior to use so as to limit the growth of biofilms and the resulting deterioration of the water quality.

TWW at **As-Samra in Jordan** is transferred to the King Talal Dam where it mixes with fresh water (long-term storage and improvement in the TWW quality).

WHICH TREATMENT SYSTEMS ARE SUITABLE FOR WASTEWATER REUSE IN DEVELOPING COUNTRIES?

Case studies highlight both the need for and the growing interest in **low-cost** and **low-maintenance** treatment systems such as lagoon systems, wetlands, sand filtration, Infiltration into aquifers.

Lagoons and aerated ponds are very common in countries such as Jordan, Tunisia and Morocco (Asano 2008). However, there is a very strong tendency for **intensive treatment technologies in large urban areas** (e.g. in Marrakesh with an activated sludge process in the reuse project for the irrigation of palm trees and the watering of green areas). Lagoon systems sometimes incorporate a Free Water Surface type wetland, providing a retention time identical to that of similar sized maturation ponds while limiting algae growth, which can clog the networks (Barcelo 2010). Soil and aquifer infiltration can also be used as a tertiary treatment after lagoons (Project 8) or after a conventional secondary treatment (e.g. activated sludge (Project 9)).

In the Southern Mediterranean, low-cost treatment options (wetlands, lagoons, sand filters or infiltration) sometimes perform poorly in terms of cost and effectiveness. These low-tech and extensive technologies are safe for water reuse, if and only if they are **properly designed and operated**. A technology must be selected based on the local conditions: availability of land (lagoons use more space than sand filters), availability of materials and resources (availability of sand for filters), etc.

High-performance, high-tech treatment systems cannot be considered as the only solution in developing countries. They are capital intensive and many specialized operators are required to run them.

The quality of the treated water, and therefore the treatment systems, must be adapted to the intended uses downstream (irrigated crops, aquaculture, groundwater recharge, etc.). Within the current context of growth of the TWWR market, the choice of treatment technologies is essential: the technology must ensure that the project is economically profitable and suitable (combination of technologies, sizing) for the intended uses. High-tech and low-tech solutions are both relevant in this approach, and several parallel chains for **several endpoints may be appropriate for multiple uses** (CGIAR 2012) (Project 2).

The cases of Korba (Project 8) and Faisalabad (Project 2) illustrate cases where the initially chosen treatment technologies were not sufficient or suitable for the intended uses. In Korba, TWW is therefore infiltrated prior to pumping and reuse by the farmers.

The selection and combination of technologies must be site-specific, arise from the study of various alternatives, be profitable, and adapted to local conditions (type of wastewater, climatic, economic, technical and organizational conditions). It is not easy to apply standard solutions for treatment technologies.

When financial costs are lower, the technology becomes more attractive. However, even a low-cost option may not be financially viable: economic sustainability is determined by the actual availability of funds to minimize operating and maintenance costs. The end goal should be to recover the total costs, although, first, specific financial arrangements such as cross-subsidies and sequential investment programs are needed (Choukr'Allah 2010).

Obviously, TWWR projects require not only an appropriate treatment, but also an efficient and well-maintained wastewater collection system upstream.

PROSPECTIVES FOR FUTURE DEVELOPMENTS

Typical patterns of reuse in peri-urban areas are often centralized urban systems implemented over large surface areas.

The development of decentralized reclamation and associated TWWR systems (small local scale) would be relevant in rural and peri-urban areas (e.g. greywater reuse at the household level for garden irrigation) but also within contexts of rapidly developing urban areas where the centralized collection and treatment infrastructure are not profitable (CGIAR 2012).

In Egypt, decentralized low-cost treatment and reuse systems are needed in remote rural areas where there are no plans for the development of centralized treatment infrastructures.

In Gaza, centralized urban reclamation infrastructures are inadequate: low-cost and household-level units have been put into place by NGOs.

Thus, further research and development should focus on:
- the development of robust, less energy-consuming alternative treatment technologies (Sanghi 2013);
- decision-makers need to be made aware of the wide range of existing and available treatment technologies that may meet their needs;
- the development of decentralized and low-cost treatment and reuse technologies (on the scale of homes and buildings).

CHAPTER 3

What are the impacts on water resources, the soil and energy?

INTRODUCTION

Water and energy resources, as well as irrigated agronomic systems (soils and crops) are interrelated:

- Water and energy are mutually dependent: water infrastructures are very energy intensive (treatments and transfers) whereas water resources are mobilized in many countries for energy production (hydroelectric dams);
- Irrigated systems consume water resources and contribute to their impoverishment in quantitative and qualitative terms; soils and crops can in turn be affected by the quality of the irrigation water;
- Energy is needed for agricultural production (tillage, fertilizer production, etc.), as well as for irrigation (pumping). Agricultural production is also a source of energy, both in the form of food crops and biomass-energy crops.

Wastewater, whether it is reused or not, treated or not, is also part of this nexus.

Raw wastewater that is either discharged into the environment or reused may have a negative and significant impact on water and soil resources; however, it may also save energy (treatment and fertilizer production is avoided - see Chapter 1).

On the other hand, by treating this wastewater, territories have access to a good quality resource that can be used to restore bodies of water or to safely irrigate. However, the treatment and pumping stages add high energy costs (see Chapter 2).

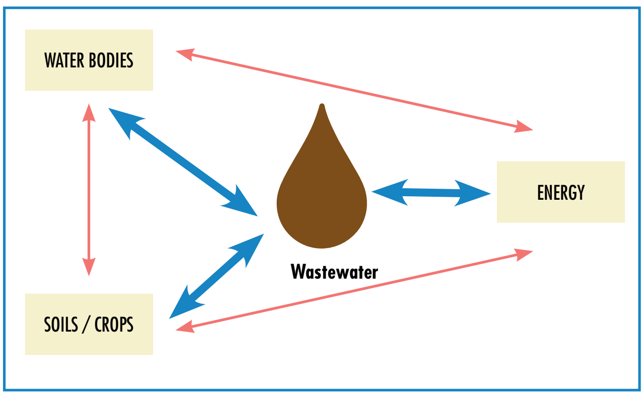


FIGURE 15: Wastewater, soils, water resources and energy nexus - Ecofilae diagram

Decision-makers must take these environmental, energy, economic and agronomic impacts into account when designing their wastewater reuse chains. Several assessment tools exist and are described in Chapter 5.

This chapter discusses the **specific interactions between wastewater reuse and the various compartments (water, soils, plants and energy resources)** (Figure 15). The developed approach consists of a comparison of scenarios - with and without reuse, where the latter is considered as a reference scenario – in order to better characterize the impacts of treated wastewater on these compartments. This approach is based on the methodologies and decision-support tools described in Chapter 5 (Cost/Benefit Analysis and Life Cycle Analysis).

INTERRELATIONSHIPS BETWEEN WASTEWATER REUSE AND ENERGY

Peri-urban agriculture is being developed in numerous developing countries. New resources need to be identified in these areas where conventional resources are often already overexploited or polluted. Heavy investments and high energy costs are required to channel new conventional resources (fresh surface or groundwater) into agricultural production areas. Locally produced wastewater (treated or not) is seen as a precious and highly valuable local resource for agriculture. Wastewater reuse and agricultural production near cities and consumers reduces both transport (water and agricultural products) and energy costs (circular economy concept).

Energy efficiency is a key factor in the sustainability of wastewater reuse projects in developing countries. The costs of electricity and energy are generally high, with an unreliable supply of electricity.

But wastewater reuse is also seen as a means of recovering energy, which in fact maximizes nutrient use efficiency (Chapters 1 and 2).

Certain wastewater treatment processes produce energy (biogas production in anaerobic digestion and methanation processes).

These interactions between wastewater and energy reuse are shown in Figure 16.

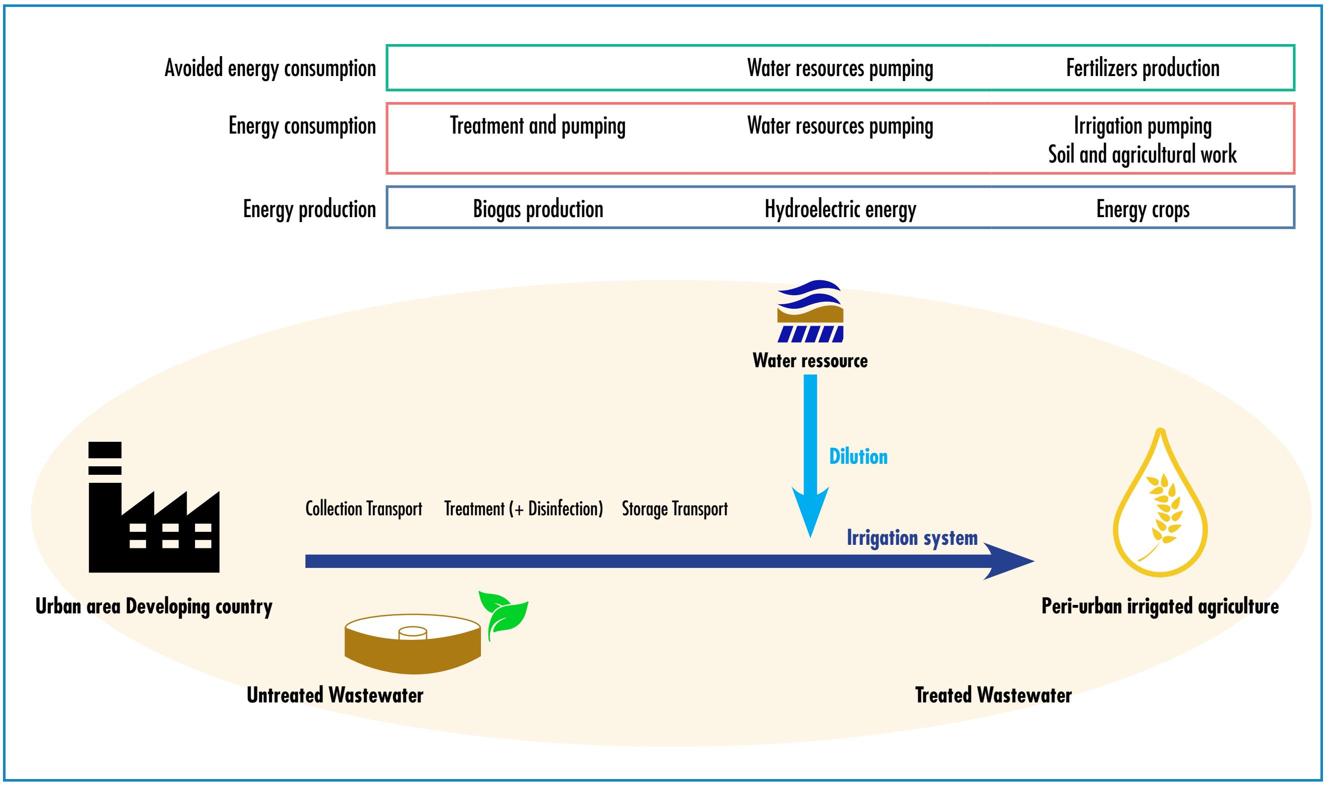
Reference scenario: conventional wastewater treatment without reuse and irrigated systems with conventional water

Energy consumption related to wastewater treatment

Most of the wastewater systems in the world require high energy consumption, especially when operating advanced treatment systems that use membranes (Ahmed 2010). It is estimated that more than 5% of the world's electricity is used to treat wastewater (Deslauriers 2004). Energy costs may represent up to 30% of the total operating and maintenance costs of water treatment plants and an increase is expected in the next few decades (Carns 2005).

The main factors determining the amount of energy consumed for the treatment are the size of the plant (treatment capacity), and the technologies used. In general, higher levels treatment result in higher energy costs and vice-versa. Energy consumption also has a cost in terms of greenhouse gas emissions and, overall, the impacts of wastewater treatment industries are significant. The cost of greenhouse gases emissions associated with the energy used in wastewater treatment is €0.02/m^3 in Israel, this value is obtained by multiplying the value of the externality (price of carbon)/kWh by the consumption of kWh/m^3.

FIGURE 16: Interactions between wastewater reuse and energy - Ecofilae diagram



Energy production through wastewater treatment

Biogas is produced via the anaerobic digestion of wastewater in activated sludge processes. CH4 and N2O gases are emitted during the degradation of organic sludge by anaerobic bacteria. In the United States, it is estimated that these emissions reach 15.5 Tg CO2-eq for CH4 (2000) and 32 Tg CO2-eq for N2O (2006). These figures account for approximately 0.7% of the total greenhouse gas emissions in the USA (USEPA 2008). This renewable energy source can be used in the same way as natural fossil gases. It is impossible to produce biogas with extensive treatment technologies (lagoons).

In **Algeria**, the **Barakis** wastewater treatment plant has a capacity of 900,000 PE. An activated sludge process was put into place. 2,200 m^3 of biogas is produced each day by anaerobic digesters. The biogas is then partially used to operate the boilers in the plant. The treated wastewater is then discharged into the Douera Dam before being indirectly reused for several purposes, including the irrigation of the Mitidja Plain (Zemmouri 2011).

Pumping for water transportation

Wastewater pumping, from its collection until its release to the environment after treatment, is very energy intensive.

The supply of water to irrigated systems from conventional water resources often consumes a lot of energy given the distance between the available water and irrigated areas (unless there is gravity flow): pumping in deep underground resources or the transportation of water over long distances may be necessary.

Energy required for fertilizer production

The use of fertilizers dates back to the early 1900s in western agriculture and their use is continuing to grow at a steady pace in developing countries. The production of fertilizers is very energy intensive (e.g. the production of nitrogen fertilizers from natural gas, the main source of energy for the manufacture of anhydrous ammonia) and is part of indirect energy consumption on farms.

Reuse scenario: an appropriate treatment for treated water reuse in agriculture

In wastewater reuse chains, the two main energy consumption categories are wastewater treatment and its transport (from its collection to its final use in the field).

Specific characteristics of wastewater treatment

A complementary treatment which increases the total energy consumption for the treatment phase is often necessary for TWWR: aeration, filtration and disinfection processes.

Anaerobic processes such as anaerobic lagoons do not require oxygen, therefore they consume less energy overall.

UV disinfection technologies widely used in developed countries are rarely used in developing countries. They add high energy costs, are dependent on the reliability of the energy supply, the provision of emergency lights, etc. The development of an autonomous solar-driven UV disinfection treatment unit should be noted.

The choice of water quality, and therefore the level of water treatment, which must be adapted to the end use of the water and to the regulations in force, must allow for the treatment-related energy consumption to be adjusted and optimized.

Treatment alternatives that reduce energy consumption are essential for the future. Natural treatments via wetlands, controlled aquifer or lagoon recharge generally have a smaller energy footprint.

The full assessment of the energy costs for the treatment technologies must specifically be carried out for the site concerned based on local electricity rates.

Pumping for water transportation

Wastewater reuse is generally done locally. Energy costs for transportation are reduced, however they must be properly assessed taking the following factors into account:

- The distances and elevations between the sources of raw wastewater and the wastewater treatment plant, and between the wastewater treatment plant and the irrigated area;
- Irrigation techniques used: high pressure systems such as sprinkler irrigation, are more energy-intensive than drip irrigation or ditch irrigation.

In Israel, the energy required to transport reused treated wastewater for irrigation was estimated at 0.5 kWh/m^3 (Condom 2012).

Avoiding the energy costs of fertilizer production

In 2006, the WHO estimated that the use of nutrients in all of the wastewater in the world would result in gains on the order of 33% nitrogen fertilizer and 22% phosphate fertilizer (WHO 2006).

The inability to recover organic matter and nutrients from wastewater is an enormous loss of resources that, instead of being used in agriculture, pollutes rivers (Volkman 2003). The closing of the loop of nutrients and organic matter by using them at the source (raw wastewater or separation during treatment) gives value to the sustainable management approach towards wastewater, a valuable resource.

Anaerobic treatment processes have been developed because they allow to better preserve biological nitrogen and phosphorus in treated wastewater.

Production of plants for biomass energy

Non-food, energy-intensive crops are ideal for reuse (salinity tolerance, limited risk of health impacts, etc.).

In Egypt, for example, several projects across the country are reusing treated wastewater to irrigate tree plantations, the bio-mass from which is used for energy purposes.

Conclusion

Compared to the importation of new resources or even the desalination of sea water, TWWR is a less energy-intensive chain.

Low-cost, energy-saving and nutrient-conserving treatment technologies, as well as the **proximity between water sources and uses**, tend to reduce energy consumption.

It would be relevant to conduct energy assessments on certain sites (single criteria analysis with an emphasis on energy) and Life Cycle Analysis methods (multiple criteria analysis, including energy balance) to obtain a better overview of all the interactions between energy and wastewater reuse (see Chapter 5). An indicator of the energy footprint of the wastewater reuse chain could then be expressed in kWh/m^3 irrigated or kWh/m^3 irrigated x kWh price or kWh/ha irrigated.

IMPACTS OF REUSE OF WATER SOURCES

Treated (and untreated) wastewater is considered as an additional essential and precious water resource within contexts of water shortage and the quantitative and qualitative degradation of surface and groundwater resources, which constitute two of the main drivers of TWWR in developing countries.

In Figure 17, different scenarios involving wastewater and irrigation (with and without reuse) and links with resources (surface and ground) are presented.

TWWR to quantitatively preserve conventional water resources

TWWR in agriculture helps to preserve and reduce pressure on local surface resources and the associated aquifers that are conventionally used for irrigation. These available resources can then be used better (or in other ways), for example to preserve the environment. In numerous coastal cities, underlying aquifers are often threatened by a high risk of salinity (saltwater intrusions or overexploitation).

In the **Mekong Delta in Vietnam**, the salinity in the water is increasing (saltwater intrusion), due to climate change. In 2012, 1.7 millions of hectares (42% of the surface) were affected by salt. Wastewater reuse in the agricultural sector is considered as an adaptation measure that responds to water shortages caused by climate change and saltwater intrusions resulting from a rise in the sea-level. Wastewater from aquaculture systems is even reused for rice irrigation in some districts (Thi Trinh 2013).

In **Settat, Morocco** (Project 4), one of the objectives of the project is to preserve groundwater resources that have long been overexploited for agricultural use.

In other places, conventional resources may be of lower quality than treated wastewater.

Discharge of untreated or poorly treated wastewater and potential indirect reuse

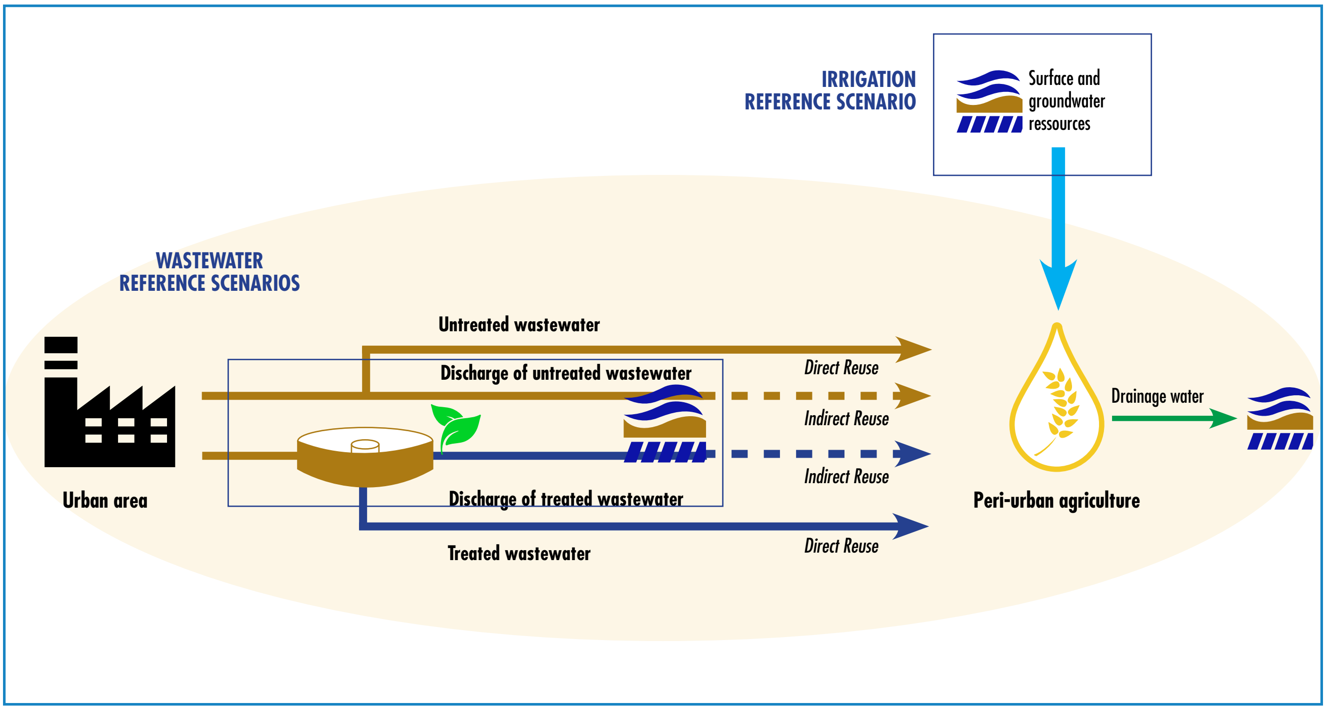
Domestic raw wastewater has long been (and still is in many cities) discharged in city outfalls, in open drains or canals, before reaching bodies of natural waters. These practices have caused environmental disasters.

In **Accra, Ghana** (Project 1), the Odaw River is the receptacle for many urban outfalls, including untreated domestic wastewater. This environmental disaster led to the contamination of the Korle lagoons downstream. For many years, farmers in many peri-urban areas have used this resource which is highly contaminated but also very rich in nutrients (directly or after dilution with natural resources).

Surface water or groundwater pollution and the associated risks of human contamination are the main drivers of wastewater treatment projects. Wastewater reuse for agricultural or environmental purposes is now becoming more and more integrated into new wastewater treatment projects, within the framework of integrated water resources management.

In the case of the **Beit Lahia plant in Palestine** (Project 9), poorly treated wastewater infiltrates groundwater resources, with a very high risk of sanitary contamination when this water

FIGURE 17 : Interactions between wastewater reuse and water resources - Ecofilae diagram



is collected. The goal of the new wastewater treatment plant in Jabaliya is to reduce the risks of exposure through better treatments and infiltration ponds.

Discharge of treated wastewater and potential indirect reuse

Treated wastewater can also be used directly for environmental or energy conservation purposes such as surface or groundwater resource recharge.

In **Bogota, Colombia** (Project 11), treated wastewater is used to maintain a sufficient flow in the Bogota River. The potential energy of the water is used by downstream hydroelectric power stations, which provide an essential part of the country's energy production.

In **Delhi, India** (Project 6), treated wastewater from the Okhla plant is partially discharged into the Yamuna River (via the Agra Canal), which improves its quality.
Overexploited aquifers can thereby be recharged with treated wastewater using infiltration ponds or by direct recharge techniques. In these cases, wastewater is often used to limit the impact of saltwater intrusions.

In **Korba, Tunisia** (Project 8), treated wastewater is used to recharge a natural lagoon and an underground resource, thereby limiting the penetration of the salt wedge. They are also reused indirectly by farmers via pumping from the underground resource.

In the northern **Gaza Strip in Palestine** (Country 5), groundwater is threatened by overexploitation and saltwater intrusions. Groundwater is recharged with poorly treated wastewater via infiltration ponds (Project 9). The new Jabalya wastewater treatment plant and its new infiltration ponds will be used to improve the quality and increase the amount of discharged treated wastewater.

As a result, more water can be pumped and reused indirectly for agriculture.

Drainage water

Wastewater, whether treated or not, reused in agriculture may percolate into groundwater and/or be drained out of the field. Surface and underground drains transport this water outside the agricultural area.

The quality of the drainage water depends on the quality of the irrigation water, agricultural practices, as well as the soil's ability to percolate and to retain and degrade the various pollutants (organic and inorganic). Salinity, microbial components and residual pesticide levels may then pose major problems. Interactions between drainage water and groundwater in terms of salinity are detailed in the paragraph below.

The drainage water collected generally has a higher salt content than the irrigation water applied, and therefore is it often necessary to dispose of (or reuse) this water in an appropriate manner.

In **Egypt** (Country 4), treated and untreated water is discharged into the Nile and into the drainage channels in the Delta. Drainage water is also collected in these drainage channels. The water is then indirectly reused for crops. Generally speaking, crops are more saline-resistant further downstream.

SALINITY OF TREATED WASTEWATER: IMPACTS AND MANAGEMENT SOLUTIONS

General impacts and challenges posed by salinity

Wastewater can potentially have negative impacts on soils, crops and the surrounding environment. Depending on their origin and the level of treatment, wastewater may still contain high concentrations of a wide range of pathogens and chemical compounds (pollutants). The chemical compounds of concern include salts, metals (particularly in the case of industrial waste), micropollutant residues, nitrogen (mainly in the form of nitrates), etc. Among all these chemical products, salinity is one of the most important factors in terms of harmful agronomic and environmental effects.

Mechanisms of salinity and the major impacts

Salinity in water is expressed in total dissolved solids (or dry residues) (TDS in g/L) or through electrical conductivity (EC in dS/m or mS/cm). It can be measured either directly in the water, or in water extracted from soil. The primary ions concerned are sodium, potassium, calcium and chloride.

Salts reduce the useful life of irrigation equipment, impacting soils, irrigated crops and the surrounding environment, including the underlying groundwater.

a) Impacts of salts on soil fertility

Irrigation with water loaded with monovalent salts (Na+ and K+) can break down the structure of the soil and leave arable land infertile by reducing infiltration rates and increasing sodium levels or exchangeable potassium levels. Soil salinization and the risk of increased sodium in the soil depend on the intrinsic properties of the soil (texture, structure, depth, organic matter content, etc.), irrigation water (composition, quantity and frequency of application), as well as climatic conditions (dry climates with high evaporation which concentrates salts in the soil) and cultural practices.

Soils are generally said to be saline when the electrical conductivity of the extracted water is greater than 4 dS/cm, and are said to be sodic when their solution has a SAR[1] greater than 13 or the proportion of sodium in the CEC[2] is greater than 15%. Kallel 2012).

b) Direct impacts of salt on crops

Salinity directly impacts crops in different ways depending on:

- the capacity of crops to extract water from soils in environments with high salinity and high osmotic pressures;
- The tolerance levels of crops for ion accumulation (the primary toxic ions are boron, sodium and chloride);
- The irrigation and water supply methods.

Leaf damage (burns or salt absorption by the leaf buds) may occur, especially if the weather is hot and dry, in the event that sprinkler irrigation is used. Thus, irrigation at night is recommended.

Plants are more sensitive to salinity in the root zone. The threshold values widely considered for irrigation water are approximately 0.7 dS/m (450 g/L) for salt-sensitive crops, 1.8 dS/m (1150 g/L) to 4.0 dS/M (2600 g/L) for moderately tolerant plants, and 6.5 dS/m (4200 g/L) for salt-tolerant plants. Therefore, the choice of cultivated species should be well thought out after assessing the quality of the water, with particular attention paid to the salinity parameters (peaks, variations and mean values).

Plant salt tolerance, the substantial decrease in yields and the associated mechanisms are well known and reported in the guidelines presented in *Water reuse for irrigation: agriculture, landscapes, and turf grasses* by Lazarova and Bahri, published in 2004 (Valentina Lazarova 2004).

If the irrigation water is saline, it is necessary to apply more water than the plants need to compensate for evapotranspiration, so that the salts are leached at depth and percolate beneath the zone root. The hydraulic conductivity of the soil must be high enough to allow adequate leaching. This parameter is an essential criterion for successful irrigation with salt water.

The higher the electrical conductivity of the water and the higher the sensitivity of the soils and crops, the higher the leaching requirements (in terms of volume and frequency). Typically, a leaching rate of 10% is appropriate for most cases, which lowers the maximum irrigation yield by 90%.

c) Impacts on groundwater

The impacts of irrigation with salt water (and associated leaching) can be harmful to groundwater resources. The leaching of cultivated soil should be carefully monitored: salts become concentrated in the leaching water that flows from the root zone to the underlying water table. This phenomenon can cause the water table to rise (recharge and osmotic capillary flow), clog the surface of the soil and ultimately create salt crusts on the surface (surface evaporation). Thus, the groundwater level must be monitored.

As a result, many populations in certain regions of the world had and still have to abandon arable land. This phenomenon is still a threat to many irrigated areas in the world.

Underground drainage and the pumping of groundwater make it possible to limit the rise of groundwater and salts and to export water outside the irrigated land. The pumping of groundwater also keeps contaminated water in the upper part of the aquifer. Conversely, the disposal of wastewater and pumped water can be a major problem depending on its quality and salt content.

Local field studies on the soil and its geochemistry are required in order to better understand and anticipate salt fluxes. The relationships between salinized drainage water and groundwater is described in Chapter 8.3.1 of the book *Water reuse for irrigation: agriculture, landscapes, and turf grasses* by Lazarova and Bahari published in 2004 (Valentina Lazarova 2004), and are not addressed in further detail in this study.

The effects of salinity on soils and groundwater are often visible after several years, depending on the soil texture, chemical and hydraulic properties, as well as the depth of the groundwater. The FAO proposed water quality standards for irrigation that take salinity and SAR rates into account (Table 3).

Impacts related to the salinity of the wastewater

In the city of **Sfax in Tunisia**, tests were carried out to assess the impacts of saline treated wastewater on different soil types (Kallel 2012) (Country 1).

1 - The Sodium Absorption Ratio (SAR) is a measure of the suitability of water for use in irrigation, as well as the sodicity of the water extracted from the soil. The formula is SAR = Na+/((Ca2++Mg2+)^(1/2))x(1/2).

2 - The percentage of exchangeable sodium is the percentage of soil Na+ in the Cation Exchange Capacity (CEC).

Treated and untreated wastewater may contain high levels of salts. The origin of the salts can be identified among industrial wastewater producers and in the network connections of the salt water (e.g. in coastal areas with the infiltration of underground salt water into the wastewater collection system). Careful management, as for conventional salinized irrigation water, must be carried out upstream of the installation of irrigation systems. The quality of the effluents should be properly characterized and assessed prior to use.

In Ouagadougou, Burkina Faso (Project 5), soils irrigated with treated wastewater are affected by the salinity.

Salinity levels vary from one municipal effluent to another, depending on the use of water in households, which can range from 30 to 300 litres per person per day in developing countries. The ions responsible for salinity (Na+, K+, Ca2+ and Cl-) are considered as non-biodegradable pollutants and can accumulate in the soil, especially if the wastewater contains industrial effluents. In certain cases, high concentrations of chloride are the limiting factor for the reuse potential, as chlorination is a tertiary treatment stage prior to distribution.

In Settat, Morocco (Project 4), high levels of salinity in treated wastewater have already been reported. The problem may become worse if industrial wastewater ends up in the wastewater collection system.

In dry climatic conditions, special attention should be paid to salts (in addition to other chemical compounds) in all bodies of water because evaporation increases the concentration. In the case of wastewater reuse, salts may become concentrated during treatment (especially in the case of extensive treatment such as lagooning), during storage, and during reuse and will stay in the soils, as well as in drainage systems depending on the rainfall and irrigation efficiency.

Salt water is concentrated in soils and is often poorly drained: as a result, salinity levels in the groundwater underlying the irrigated plot may be up to 5 times higher (for an irrigation efficiency of 80%) than in the applied wastewater itself. Therefore, special attention should be paid to the long-term effects of irrigation with wastewater (soils and groundwater). Soil clogging due to high levels of suspended solids in wastewater and the deterioration of the soil structure may also occur.

Nevertheless, irrigation with treated or untreated salinized wastewater can be sustainable if proper management is implemented. A new balance in the soil chemical parameters then takes place.

Solutions

Many wastewater reuse projects (with a treatment of varying intensity, or even no treatment) are faced with salinity problems. Solutions (Figure 18) may be put into place at different levels in the reuse chain to control and limit agronomic and environmental impacts.

TABLE 3: Standards for irrigation water quality for crops - FAO Guidelines - FAO, 1998[1]

POTENTIAL IRRIGATION PROBLEM		UNITS	DEGREE OF RESTRICTION ON IRRIGATION		
			NONE	Slight to Moderate	SEVERE
Salinity (affects crop water availability)[2]					
	EC_w	dS/m	<0.7	0.7 - 3.0	> 3.0
	TDS	mg/L	< 450	450 - 2000	> 2000
Infiltration (affects infiltration rate of water into the soil, evaluate using ECw and SAR together)[3]					
SAR	0-3	and ECw =	> 0.7	0.7 - 0.2	< 0.2
	3-6		> 1.2	1.2 -0.3	< 0.3
	6-12		> 1.9	1.9 - 0.5	< 0.5
	12-20		> 2.9	2.9 - 1.3	< 1.3
	20-40		> 5.0	5.0 - 2.9	< 2.9
Specific Ion Toxicity (affects sensitive crops)					
	Sodium (NA)[4]				
	surface irrigation	SAR	<3	3-9	>9
	sprinkler irrigation	meq/l	<3	>3	
	Chloride (Cl)[4]				
	surface irrigation	meq/l	<4	4 -10	>10
	sprinkler irrigation	meq/l	<3	>3	
	Boron (B)	mg/l	<0.7	0.7-3.0	>3.0
Miscellaneous Effects (affects susceptible crops)					
	Nitrate (NO_3-N)	mg/L	<5	5-30	>30
	Bicarbonate (HCO_3)	meq/L	<1.5	1.5-8.5	>8.5
	pH		**Normal Range 6.4 = 8.4**		

1 - Adapted from FAO (1985)
2 - ECw means electrical conductivity, a measure of the water salinity, reported in deciSiemens per meter at 25°C (dS/m) or in millimhos per centimeter (mmho/cm); both are equivalent.
3 - SAR is the sodium adsorption ratio; at a given SAR, infiltration rate increases as water salinity increases.
4 - For surface irrigation, most tree crops and woody plants are sensitive to sodium and chloride; most annual crops are not sensitive. With overhead sprinkler irrigation and low humidity (< 30 percent), sodium and chloride may be absorbed through the leaves of sensitive crops.

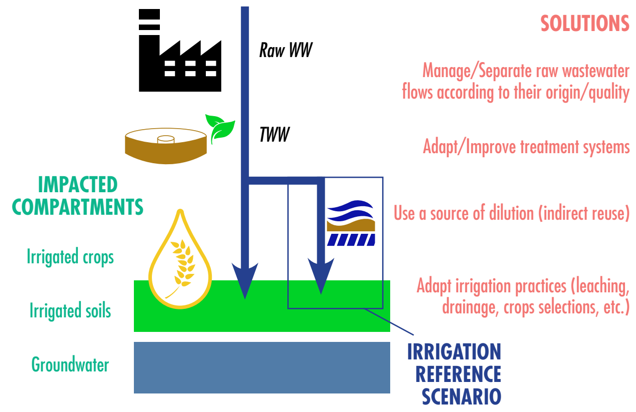


FIGURE 18: Salinity in wastewater reuse: impacted compartments and existing solutions - Ecofilae diagram

Control of the collected wastewater quality at the source

Urban domestic wastewater must be protected by diverting or separately treating poor quality industrial effluents and brines. The infiltration of brine water into leaky sewers (common in coastal cities) and the use of softeners or household products, the main sources of salt, must also be limited.

At the **Lamzar** wastewater treatment plant in **Agadir**, Morocco, the discharge of effluents from the fish industry (cannery) into the wastewater network results in a high level of salinity in the reused treated wastewater.

Adapt and improve the treatment systems

Treatment systems must be adapted for downstream use (bottom-up approach).

In the **Pikine District of Dakar, Senegal** (Project 7), raw wastewater has long been reused directly to irrigate vegetable crops resulting in soil and groundwater salinity problems. The use of treated wastewater is planned to improve the situation.

Extensive treatments such as lagooning or wetland systems may be inadequate in dry climates where evaporation is high, resulting in concentrations of pollutants and salts. They should be designed accordingly with short water residence times.

In **Faisalabad, Pakistan** (Project 2), farmers rightly consider wastewater treated by the lagoon system as too saline for irrigation. They prefer to use untreated wastewater directly, as it contains more nutrients and organic matter.

Technologies with the best treatment efficiency are seen as a way to improve the quality of the wastewater (at higher costs), but the elimination of brine (concentrates of salt) although sludge is still a major concern. With the use of membrane filtration or other desalination processes, decision-makers would be tempted to use the water for higher value-added uses than agriculture. Smaller volumes that have higher salt concentrations (concentrates resulting from the treatment) are then difficult to use in agriculture or industry, but can be transported at a lower cost over long distances to an appropriate discharge point (salty environment, the sea).

In order to prevent the salinization of land and water bodies with reuse sustainability in mind, Israel partially removes the salt from reused wastewater using membrane processes.

Implementation of appropriate agronomic and irrigation practices

a) Specific cultivation practices to limit impacts on the soil

Additional irrigation must be applied to ensure efficient soil leaching and to drain salts out of the root zone. As a result, it is necessary to monitor the soil and underlying groundwater (see the above paragraph). Salt leaching may also be combined with nitrate leaching into the aquifer. For all these reasons, the monitoring of groundwater underlying areas irrigated with wastewater is a key environmental performance indicator for wastewater reuse projects.

The structure of the soils affected by salinity can also be physically maintained by specific cultivation practices such as deep tillage, the addition of organic residues, or the direct incorporation of gypsum or indirect sulphuric acid prior to leaching.

b) Changes in crop rotation

Crop rotation and crop selection should be directed towards salt-tolerant crops, otherwise the yields may also be affected. Farmers need to identify the acceptable yield loss. An indicator for the impact of salinization could be the yield loss per hectare multiplied by the selling price of agricultural products.

c) The choice of irrigation system

The best irrigation performances with salt water are obtained with localized irrigation techniques (drip). However, clogging is likely to occur.

d) Sequential irrigation and appropriate crop choices

Drainage water is often more concentrated than irrigation water. The collected drainage water can be used in various crop sequences along a course of water that, from upstream to downstream, starts with salt-sensitive crops, then salt-tolerant crops and last, halophytes.

In Egypt (Country 4), the salinity of the water in the Nile Delta increases as it moves further downstream from the delta due to the discharge (controlled or not) of drainage water and treated or untreated domestic and industrial wastewater. As a result, crops have been adjusted: rice, wheat and maize are grown upstream, whereas aquaculture is the main agricultural activity in the coastal area.

e) Pilot tests prior to large-scale implementation

If there is doubt regarding the impacts of wastewater salt on soils, crops, their productivity, and on the nearby environment, a test phase can be carried out locally on specific crops, soils and water sources. A pilot scale study could be implemented so as to overcome technical constraints related to salinity management. It would then be possible to consider the suitability of the crops, agronomic and irrigation practices and the level of treatment as well as the projected economic success, prior to implementation on a large scale.

Use of an intermediate dilution source

Mixing wastewater with another water source can be a way to reach acceptable salinity levels for irrigation water.

Jordan (Country 3) built wastewater treatment lagoons with TWWR in mind. High evaporation rates in lagoons have increased the salinity levels of TWW. As a result, agricultural yields in the Jordan Valley have decreased. The As-Samra wastewater treatment plant was then built in 2008 through the use of conventional activated sludge, prolonged aeration basins and lagoons are kept as maturation ponds (disinfection). TWW is then diluted in the Zerqua River and in the King Talal Dam prior to indirect agricultural reuse in the Jordan Valley (Bashaar 2007).

In **Korba, Tunisia** (Project 8), at first, the treated wastewater was too salty to be directly reused in agriculture. Indirect reuse after groundwater recharging and pumping was therefore implemented.

Another strategy may be to alternate the use of wastewater with another water source. However, this requires doubling the transportation systems and the availability of effluents controlled by the alternating application schedule.

Jordan - As Samra plant © Condom, 2014

CHAPTER 4

Organization, institutions and regulations

Research on treated wastewater reuse (TWWR) in the MENA region has so far scarcely drawn from social science in general, and from policy analysis in particular. Reflections on the political-institutional dimensions of reuse have mostly been confined to a few pages in international reports (see for example: UNEP, 2003; USAID, 2004). When analysts have tackled these dimensions most extensively (WHO, 2006) they have been content with describing existing institutional architectures and identifying a few general regulatory "bottlenecks". As a consequence, recommendations have tended to be generic and procedural (such as advocating a clearer allocation of prerogatives, or asking for an early consultation with all stakeholders).

What has been lacking, by contrast, are empirical analysis of the TWWR policy-making process. Yet only by investigating policy-makers' existing practices, interests and worldviews, as well as the various legacies they confront, will we be able to make policy recommendations that are grounded in specific contexts, and therefore likely to have some effect. The point of departure is to recognize that TWWR, despite the many benefits that it is expected to bring, is not merely a technical issue, but also a deeply political one. It competes with other solutions to water scarcity; it reorganizes bureaucratic prerogatives; it reallocates costs and benefits; multiple actors intervene to orient it, with different priorities; it can run against existing arrangements and worldviews; its implementation requires creative adjustments and "practical authority" to solve new problems as they arise (Abers & Keck, 2013). In short, putting TWWR into policy is necessarily a messy process filled with uncertainties.

Due to the paucity of research on the "politics of reuse", this section aims not only to present some political, institutional and regulatory facts for the MENA region, but also to sketch some research questions that should be better addressed in the future. It calls attention to six issues in particular: the possibility of persistent agenda-setting with few projects adopted (1); the complex politics of projects definition (2); existing legacies and routines (3); regulatory process and trade-offs (4); implementation gaps (5); and the political economy of TWWR (6).

FROM AGENDA SETTING TO POLICY DECISION: AN UNEVEN PROCESS IN THE MENA REGION

In his classic work, John Kingdon (1984) looked at how some issues came to the attention of governments. His theory includes three separate, but loosely-coupled streams – the problem, the policy and the political stream – that need to converge to open a "window of opportunity" for reform. However, Kingdon makes clear that the opening of such a window only implies that various options will be discussed and that some decisions will be considered: it does not follow from this process that specific projects will be adopted, let alone implemented. In other words, there is no straightforward path from agenda-setting to policy decisions: they are many "near-miss critical junctures" when "change is possible, considered, sought after but fails to materialize" (Capoccia, 2015, p. 165).

In the case of TWWR, a confluence of the three streams can certainly be observed in most MENA countries. According to Kingdon the problem stream is where particular problems get identified – due to focusing events, changes in indicators, or other items. The sociology of social problems (Hilgartner & Bosk, 1988) has insisted on the fact that in many cases no objective threshold of seriousness could automatically trigger a government reaction to a problem. Rather, many complex social activities are required including the production by scientists and experts of data, indicators, causal schemas and scenarios for the future. As for TWWR two distinct problems have caught the public attention. The first one is the steady decrease of water availability per capita due the decrease of rainfall, economic development, urbanization and population growth. This alarming trend has been increasingly documented and publicized (for a recent example: WRI, 2015). The second one has been more recently constructed as a social problem: it is the uncontrolled reuse of untreated wastewater in peri-urban areas. Here, too, scientists and experts have been key to publicize the problem, much as in the classic "anticipation" model of agenda-setting (Garraud, 1990). They have made visible, for instance, the fact that in Egypt drainage water, mixed with "fresh" Nile water and wastewater, is intensively reused downstream for several purposes including the irrigation of crops. Small-scale reuse systems for greywater or bayaras (septic tanks) are also being developed in rural areas where coverage of water treatment networks and plants is not planned to be expanded in the next decades. In Morocco also, it was estimated in 2009 that 7.200 ha of crops were irrigated with untreated wastewater in peri-urban areas (Marrakech, Meknes, Oujda, Fes).

The policy stream contains a set of available options. Here some actors have to transform vague ideas into politically, economically and technically viable solutions. This process has also been largely successful as TWWR is now widely perceived to be a credible solution to various inter-related problems. It is especially seen as a way to capitalize on the urbanization process and to reduce pressures on good-quality water, while filling up some plants' organic and mineral needs. Political discussions now are less on why TWWR should be promoted at all, but on how it should be promoted.

Finally, the political stream refers to the priorities stated by political actors such as ministers and their cabinet. Here policymakers must find both the motives and the opportunity to select, among competing social problems and competing policy solutions, one "couple" of problem-solution and to turn it into policy. They may supplement their own beliefs with their perception of public opinion and the feedback they receive from various interest groups. This political aspect of agenda-setting is based on considerations of political legitimacy, credit-claiming and possibly political competition.

TWWR has therefore been put almost everywhere on both the legislative and the governmental agenda, even though in most countries the legal framework is still widely seen as incomplete. National water strategies and water laws do refer to TWWR. They allow for the State to financially subsidize projects. Where countries differ widely, however, is in their propensity to translate this broad institutional agenda into specific projects.

Making sure these streams do connect, and in a sustained way, is often the task of specific policy entrepreneurs (Kingdon, 1984). It would therefore be important to gain a more specific view of exactly who these policy entrepreneurs are in the MENA region, what are their specific views of TWWR and how they pursue their objectives. There has been so far no sociological study on this dimension. More generally, if TWWR has been put on the agenda in most MENA countries, it probably has not been everywhere thanks to the same actors, through the same political processes and with the same intensity. This would justify some comparative studies of agenda-setting.

Beyond that, however, MENA countries differ widely in their capacity to transfer this shared interest into specific policy decisions. At one extremity for instance, Jordan is reusing up to 85% of its treated wastewater. All of the treated wastewater collected from the two main cities (Amman and Zarqa) is mixed with freshwater and used for unrestricted irrigation in the Jordan valley. In an intermediary position, Tunisia has developed the use of treated water for more than 30 years, as the treatment sector has undergone continuous development. Today approximately 24% of treated wastewater is used for irrigated agriculture, all Tunisian golf courses use treated wastewater, and more than 3.000 ha of crops and forests were irrigated in 2009. By contrast, Morocco would seem to be a laggard, although it is slowly catching up as many wastewater plants, mostly of which use lagoon treatment process, are currently under construction in medium size cities. Accounting for these different trajectories is therefore a crucial task. It requires going beyond agenda-setting to look at the specific politics of project adoption.

THE POLITICS OF PROJECT ADOPTION

Many experts tend to look at the adoption of TWWR projects in functionalist terms. In this view, the higher the water scarcity, the stronger the political response and the share of treated wastewater that will be reused. Jordan and Israel, two of the most water-stressed countries in the region and also two front-runners in the field, seem to confirm this pattern.

However, policy analysis tells us that similar "adaptive pressures" seldom lead to similar, predictable, policy responses (Radaelli, 2003). First, because policy-makers can seldom be described as fully rational: their preferences are multiple, often contradictory and shaped by ideas and representations as much as (often elusive) material interests. Second, and most importantly, because the decision-making is the product of multiple actors in complex interactions. Project adoption thus requires the assembling of a coalition between actors with different sets of priorities (Hall, 2009). We therefore need to understand how individual actors shape their preferences relative to TWWR, and how they set out (or not) to building coalitions.

This question is all the more daunting in the case of TWWR as, like environmental policies in general, there is little a priori "sectorization" of the issue while, the number of intervening actors tends to be extremely high (Lascoumes & al., 2014). Crucially, these actors also span multiple levels of action, and they include public as well as non-public actors. Public actors typically include:

- Local water and sanitation companies.
- Local governments who are generally formally responsible for sanitation.
- The Ministry in charge of water and the environment, and its local administration.
- The Ministry of agriculture and its local administration, responsible, inter alia, for the planning of irrigation development programs and management of irrigation schemes.
- Water basin agencies, many of which have to authorize the disposal of reused water for specific purposes.
- International donors financially contributing to the project and making studies.
- The Ministry of Health who monitors water standards and water-related diseases.
- The Ministry of Finance who manages the tax base for public operators and concession contracts.
- The Ministry of Economic Affairs that participates in the regulation of water rates.
- The Office for food security, who generally enjoys a substantial degree of autonomy relatively to either the Ministry or Health or the Ministry of Agriculture.
- Public research institutes in hydrology, biology and agronomy.

In many countries, the Interior ministry is likely to play a significant role as well. In Morocco for instance, it coordinates the National Sanitation Plan (PNA) together with the Ministry of Environment. It also provides direct technical support to many local water operators.

Furthermore, the process of project selection and definition also involves many non-public actors. These actors especially include irrigators' organizations, urban users' organizations, consultancy firms involved in preliminary studies as well as various national and international experts. We therefore need to know more on how these actors form their preferences and how they interact: are these interactions more or less institutionalized, following some well-identified set of rules and patterns? On the contrary, to what extent ad hoc negotiations (and coercion) predominate?

Among the many divides surrounding TWWR, the urban/rural one can be the deepest. Generally speaking, it should be noted that reuse requirements are not always consistent with the short-term interests of sanitation companies, or even the municipalities. Reuse is costly and often more demanding, at least for some parameters, that the compliance with some maximum values. Planning for reuse can also lead, for economic reasons, to choose another treatment process over the one that would have been privileged otherwise.

As a consequence, wastewater treatment plants are generally built by urban operators with little regard for reuse options. In many countries such as in Morocco, most of sanitation projects do not integrate reuse in the early planning. TWWR options are only considered later, with all the constraints entailed by the fait accompli. Water disposal can therefore happen far away from potential areas of reuse, or in low-level points of discharge requiring important pumping to be reused.

Clarifying responsibilities?

It is worth repeating that multiple actors in complex (formal and informal) interactions characterize most public policies, especially in the environmental field. In policy matters, prerogatives tend to overlap and be interpreted differently by different actors. Vague calls for "policy integration" do not make the problem disappear. However, this should in no way prevent us from reflecting, as many have already done, on the ways to clarify prerogatives, to build more stabilized patterns of interaction and to forge agreed mechanisms for settling disputes. Morocco, for instance, claims to have succeeded in establishing protocols of agreement binding the partners and specifying their responsibilities and roles in various projects such as in Settat, Tiznit and Guelmim. It would be interesting to know more about these protocols and how they were elaborated.

Some have urged to consider the opportunity of setting up a permanent national interagency committee under the auspices of a lead ministry (the Ministry of Agriculture or water resources), or possibly as a separate organization (benefiting both from public and private funding). This committee would take responsibility for national planning, programs coordination, providing quality information and ensuring the compliance with existing norms. It would also be possible to more clearly assign responsibility for TWWR in agriculture or part of it to existing organizations, such as the national water agency.

Such technical committee may also be set up for each project at the local level. In the city of Ouarzazate in Morocco, for instance, the reuse project proceeded alongside the creation of a "Local technical committee for monitoring project" (CTLSP). The CTLSP was established under the auspices of local authorities with the participation of provincial technical departments. It has been acting as a local institution whose members meet on a regular basis. The perspective of such an inclusive committee can be key for project adoption, as all actors can be persuaded that they will have a voice in the implementation process and will not be marginalized.

However, it is not enough to point out some general determinants of project decisions. What matters is also the determinants of local and national variation in content. How do policy-makers take into account local institutional, geographical and agricultural specificities in their decisions? How to account for the fact that Tunisia, for instance, has come to mobilize TWWR for wetlands rehabilitation and groundwater recharge much more than other MENA countries?

Much remains to be known, therefore, about TWWR decision-making processes. It is necessary to delve into specific projects to better understand the mechanisms at play. In Morocco for instance, the projects of Settat (300 ha of irrigated maize, wheat and olive trees) and Marrakech (for golf courses) would provide for interesting case studies.

STRUCTURING OF THE POLITICS OF REUSE: LEGACIES AND ROUTINES

Some strands of political science have insisted on the way actors' interactions tended to be heavily shaped by institutions (formal and informal) that had emerged long ago (Steinmo, 1992; Thelen and Mahoney, 2010). In the case of TWWR, we know remarkably little about these legacies and the way they can constrain or enable project adoption. These legacies can refer, for instance, to the organization of formal bureaucracies. In many MENA countries urban and agriculture bureaucracies have developed along different paths, with different corps of engineers at their helm and little contact with one another.

Furthermore, cognitive legacies are often embedded in these formal organizations. In Morocco for instance, dam-building and the quantitative management of water have been given the absolute priority from the 1960s onwards. Wastewater therefore remained distinctly out of bureaucrats' cognitive map, even though untreated wastewater has been de facto increasingly resorted to by peri-urban agriculture, as urbanization proceeded.

The legacy of other policy priorities may have generated a lack of knowledge and awareness of wastewater effects and risks that may also pose further obstacles to adoption. Thus, according to the Moroccan water ministry, many water and agriculture bureaucrats do not have adequate knowledge on environmental risks posed by wastewater, such as effects on soil structure, groundwater salinity or health risks (chemical, microbiological, epidemiological risks). They are also self-admittedly unaware of monitoring and control requirements (Kingdom of Morocco, 2011).

REGULATING RISKS: AN ONGOING (AND MESSY) PROCESS

If mentioning TWWR as a potential solution in a law and/or a national water strategy can be a sign of heightened public attention, these texts usually provide no more than a general framework. Regulations are where really crucial choices are discussed and made, choices that will directly shape the structure of costs and benefits of economic actors.

TWWR regulations have to cover a dizzying amount of topics, affecting both the (food and water) products and the processes. Broadly speaking they can be divided up in three categories: technical standards, economic incentives and property rights. This distinction is no more than a clarifying tool, as many technical standards are also de facto economic incentives, as are property rights.

Technical standards define construction norms, water-treatment processes, maximum values of parameters for wastewater quality, restrictions on products for health and safety reasons, application methods, minimum distances between irrigated areas with treated wastewater and activities or environments to protect, food hygiene and monitoring methods, among others.

Economic incentives include tariffs paid by urban users for the removal of wastewater, as well as subsidies, incentives and fines. Fines may be imposed on businesses and individuals to penalize emissions and/or risky behaviours and practices in the field of hygiene, causing risks to people and the environment.

Finally, relevant property rights are property rights for wastewater, including public regulation of their use. They can also include property rights over land.

As for the other issues, we are still in need of some detailed studies of the regulatory process, all the more so in a comparative perspective. There is a strong "policy transfer" component to this issue (Dolowitz & Marsh, 2000), as WHO guidelines designed to facilitate international trade are by now a common source of inspiration. Questions to be answered include: to what extent do the adopted norms and standards directly reflect the vision and interests of some dominant players? On the contrary, to what extent are they the product of broad compromises based on mutual concessions? Do technical standards evolve (or not) along with progresses made in the scientific field? And how can we interpret the persistence over time of regulatory voids and ambiguities?

Among practitioners, three issues seem to stand out in particular. The first one, fairly classical, is about the appropriate level of standard requirements. It is related to what constitutes an "acceptable risk", which can be hotly debated. In Morocco for example, standards of water quality for irrigation are very restrictive in terms of quality for categories A and B on intestinal nematodes and helminth eggs: it requires their total absence in 1 litre, as compared to the ones recommended by WHO which are less stringent: <1 litre. Here adopting high standards can be a way to publicly signal seriousness in minimizing risks. While some will deride this move as neo-Hygienism (Aggeri, 2005), others will praise it as a welcome application of the precautionary principle.

High standards have very practical consequences. In Tunisia, for example, TWWR is forbidden for high value crops such as vegetables, causing farmers to return to more expensive conventional water resources. In Egypt, the current regulation is very restrictive and limits treated water reuse to the irrigation of trees plantation. The upcoming revision should include the irrigation of crops and groundwater recharge.

Another field of controversy is related to the question of who should have the power to regulate what. For example, to what extent should local governments be able to issue permits, conduct inspections and establish restrictions on authorized crops? And who should have the capacity to issue permits for the use of wastewater from a public distribution network in agriculture?

A third line of debate spurs more "puzzling" (Heclo, 1974, 306) than controversy proper. It discusses the degree to which norms should be adapted to local conditions. To what extent should standards be differentiated along types of uses? Some distinctions are everywhere made. For example, crops that are consumed raw (fruits and some vegetables) or areas open to the public are subject to more demanding quality standards that crops consumed after processing or intended for non-food uses (horticulture). But not all countries define four categories of use such as France does.

These debates only further complicate a process that is already hindered by high technical complexity and scientification, even though knowledge is still incipient. Regulating risks therefore appear as a protracted and uneasy process. Even a front-runner like Jordan still needs to transform many guidelines into effective standards and specific threshold values. But virtually all MENA countries still have widely incomplete and often partly inconsistent regulations. This is the case of Morocco, particularly as regards the obligations of local governments and users, the regulation of tariffs and plant operation, the monitoring of discharges, sludge management and sanctions for non-compliance with existing standards (including industrial discharges).

THE IMPLEMENTATION GAP: CAPACTIY, COMPLEXITY AND CONSENT

That implementation is always filled with unintended effects and creative derivation has been known for long (Pressman & Wildawsky, 1973). This is the case because regulations are necessarily insufficiently specific and ambiguous, while hierarchical control needs always be supplemented with informal adjustments (Hill & Hupe, 2002). Furthermore, at this stage, new actors assume some new importance, such as local managers and engineers, who need to be incorporated in the implementation game.

Lack of bureaucratic capacity to enforce and monitor policy is something common, but it is especially prevalent in weakly bureaucratized State such as in the MENA region. It can be compounded by particularly high standards of monitoring initially designed to signal a strong commitment to mitigate risks. In Morocco for instance, the minimum number of samples that are required for treated wastewater is 4 per year for heavy metals but 24 times a year for fifteen bacteriological, parasitological and physicochemical parameters.

In the specific case of TWWR, monitoring is also inherently difficult due to the nature of the pollution at stake: rather than massive and visible it is mostly diffuse, coming in infinitesimal doses of chemical pollutants. The dividing line between the "normal" and the "pathological" is therefore particularly hard to draw (Aggeri, 2005).

We should not content ourselves, however, to highlight the distortions between the rules and their application, in both a top-down and normative perspective. We should rather look directly and without preconceptions at actually-existing practices, as many researches have set out to do (Lipsky, 1980; Dubois, 2008). We need some fine-grained studies on exactly how the health and environmental monitoring operate concretely, on how public, private and social actors routinely interact on an everyday basis, and on how they settle their micro-disputes.

We also need to compare implementation in various countries. If, for instance, and as some experts argue, Tunisia has taken more actions than any other MENA countries to mitigate environmental and health risks, we need to understand why.

Producing consent

Another key issue related to projects implementation has to do with the consent of local farmers. Here we should take into account not only the direct beneficiaries of the projects, but all the farmers likely to be affected, directly or indirectly, by a TWWR project. We are in need of researches that analyse the evolving interactions between governments and local farmers, the way the former manage to structure the action of the latter and with what form of legitimacy. We also need investigations "from below" on the way farmers perceive specific projects and the political and economic restructuring that they entail.

Do they also consider "acceptable" the price to pay, especially for those who used to rely on (untreated) wastewater before? What is, especially, the attitude of users' associations?

We know very little on these issues in the MENA region. In Morocco, it seems that competition with the free use of conventional water, combined with the limited efficiency of treatment plants has been responsible for the failure of several water reuse projects, especially in small communities. In Jordan, many illegal uptakes still occur on the way between WWTP and reservoirs where it is diluted.

It is a fact, more generally, that conflicts have arisen in other settings. In Pakistan, many lawsuits have been filed by local water companies against local farmers, jeopardizing their (illegal) use of wastewater. Following these trials, farmers were forced to pay to dispose of wastewater or to forgo their use, which arouse discontent. In the city of Faisalabad, however, a group of wastewater farmers gained an appeal against one of these judgments, having proved that they had no access to any other suitable source of water (Ensink et al., 2004).

To try to mitigate the implementation gap, policy-makers have stressed the need for better information and education programs so as to generate more support from farmers (and the general population) for sanitation development efforts. Many have also stressed the need for a better participation of "local communities" in policy design and implementation, for example in Tunisia and Jordan. It might be interesting to analyse these "discursive policies" (Schmidt, 2008) aiming at producing social acceptance.

The political economy of TWWR investigates who pays what and with what level of acceptance. This is far from easy, as externalities (both positive and negative) are as tricky to measure here as they are everywhere. How to assess positive externalities such as reducing the degradation of water quality, decreasing health risks and generating additional nutrient inputs? The potential economic gains also depend on the availability and cost of mobilizing conventional water resources, and on the general level of water stress.

As a rule of thumb, however, it is almost impossible to recover the costs of tertiary treatment and monitoring only by selling water. Projects therefore need to be subsidized, and in such a way that prices will be competitive for farmers. In Morocco for instance, the costs generated by the upstream part of reuse projects (additional works for the wastewater treatment relative to the secondary level, operation, maintenance, testing, etc.) typically range from 2.02 to 2.40 DH / m^3 of wastewater treated according to the discount rate that is used.

Here again we run up into issues of monitoring standards, as the frequency of analyses and measures can generate high costs that need to be paid by someone.

A prevalent problem, however, has to do with the general absence of an institutionalized framework for costs (and benefits) allocation. Rather, the allocation tends to be done on an ad hoc basis for each case, according to contingent negotiations (and less contingent power relations). One exception is Israel with its national cost-transfer policy.

THE POLITICAL ECONOMY OF REUSE

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Morocco – Experimental set-up of the Agronomic and Veterinary Institute Hassan II for TWWR
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CHAPTER 5

Which tools and which methodologies are used to make assessments and decisions?

INTRODUCTION

Wastewater reuse poses multiple and complex questions. The assessment and integration of the various components of a project (see the sustainability equation in Figure 2) requires specific decision-making tools and integrating methodologies. The main limitation for the development and widespread deployment of reuse projects is the lack of this type of tools.

Appropriate **multi-impact and multi-sectoral approaches** would help decision-makers and managers to assess the **sustainability of projects** and to identify and select the best reuse options to be implemented.

A methodological framework, including a road map (Figure 19 below) and a checklist (Table 15 in the Blue Plan Papers 11) for the project assessment was developed in the Blue Plan Papers 11 (Condom 2012)[1]. Its goal is to help managers implement their treated wastewater project, step-by-step, and to compile the information needed to respond to the key issues in the early stages of the project implementation. Once the answers have been obtained, the checklist becomes a decision-making and information-sharing tool. It also constitutes a common working medium for all of the actors involved in the project.

Monitoring and operational tools, after the implementation of a TWWR project, have not been identified and need to be developed.

1 - https://planbleu.org/sites/default/files/publications/cahier11_TWWR_en.pdf

The tools and methodologies described in this chapter are assessment tools. They must be used and implemented before the infrastructure is put into place so as to help define and select the project. Different options for wastewater reuse and non-reuse can be compared in terms of environmental, economic and health impacts. It is often necessary to conduct design studies prior to carrying out these assessments: specific dimensioning tools (treatment, network, irrigation systems, and irrigated surfaces) already exist for all components of the wastewater reuse chain.

The most common and inclusive tools and methodologies used in wastewater treatment and reuse to integrate economic, environmental and health risks are primarily:

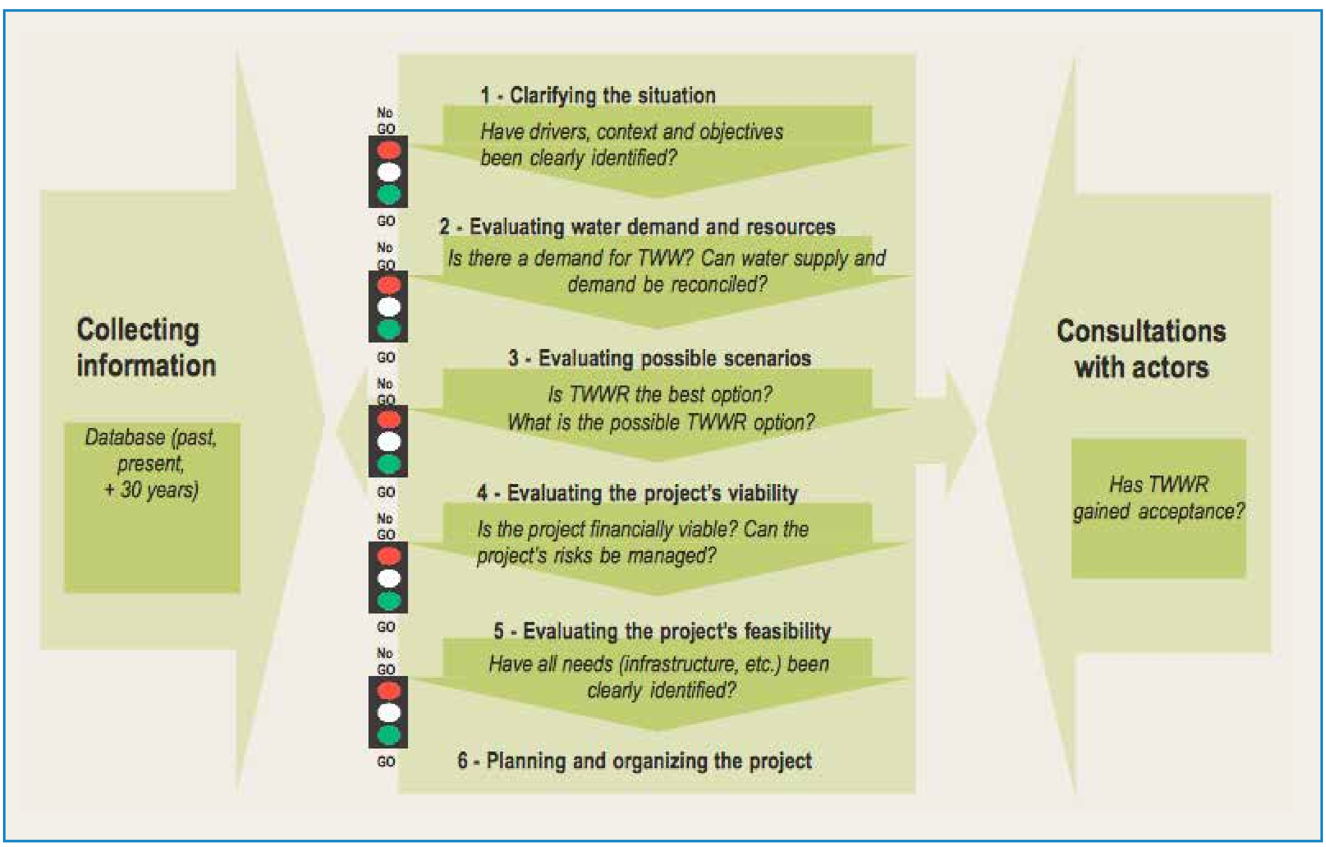
- Environmental Impact Assessment (EIA);
- Risk Assessment;
- Cost/Benefit Analysis (CBA);
- Life Cycle Analysis (LCA), an emerging and invaluable methodology with broad application potential in the field of wastewater reuse.

DATA AND INDICATORS

Complete free databases

Sato et al. (2013) found that reliable wastewater data were limited and missing despite the forecasted market growth for TWWR throughout the world (experience feedback, data

FIGURE 19: Outline for the assessment of a treated wastewater reuse project – Blue Plan Papers 11



on wastewater characteristics, data on cultural practices, etc.) (Sato 2013). A framework for collecting, storing and analysing data must be developed in order to share experience feedback.

Identifying and defining indicators

The various assessment tools use specific indicators. They make the decision-making process easier, by simplifying or summarizing the key characteristics, by representing the phenomena of interest, and by quantifying, measuring and communicating the relevant information (Gallopin 1997). The indicators used to assess the sustainability of wastewater reuse projects have been described in the Blue Plan Papers 11 (Condom 2012). However, they must always be adapted to the specifications of each project because their use depends on factors related to the geographical territory, its environmental context, the culture of the community, end users and other stakeholders.

COST/BENEFIT ANALYSIS, AN ECONOMIC ASSESSMENT TOOL

The methodological frameworks for the economic (social CBA) and financial (private CBA) assessments adapted to treated wastewater reuse projects are briefly described below and in more detail in the Blue Plan Papers 11 (Condom 2012).

The economic analysis is used to decide if a project is to be implemented or not and to determine if it is economically justified, i.e. if the benefits exceed the costs (Condom 2012). Two of the steps used to analyse a treated wastewater reuse project are the economic and financial Cost/Benefit Analyses (CBA). Social costs and benefits, environmental externalities and impacts on human health can be assessed (identification and monetization processes) within a social CBA. The goal of a financial analysis is to determine if a project can be funded and how. The financial analysis looks at financing structures via the private CBA (Condom 2012). It seeks to identify adequate financing mechanisms (appropriate water tariffs, the implementation of subsidies, etc.). Investment, operations and financial flows are included in the analysis.

Uncertainties, assumptions and financial and economic risks can be addressed using sensitivity analysis methods (multiple scenarios or the Monte Carlo method).

At the moment, TWWR projects are often undervalued compared to other water-related projects, particularly as the social, environmental and health benefits such as watershed protection, local economic development, and the improvement of public health have not been properly quantified (World Bank, 2010).

Cost-benefit analyses are rarely carried out in a comprehensive manner. Undoubtedly, this has resulted in the abandonment of projects that would have been economically viable. Indirect costs and benefits, as well as social and environmental externalities, must be incorporated into the analyses. In Egypt, no CBAs incorporating all indirect costs and benefits were carried out.

In many developing countries, the CBA will no longer try to determine if WWR is profitable or not, but will identify and help select the most cost-effective and sustainable scenarios. Nevertheless, cost/benefit analyses were carried out in France (ONEMA - Loubier 2013) and Italy (Verlicchi 2012) on several TWWR projects, while stressing the need for new methodological developments and more experience feedback.

In certain regions (Mediterranean), particularly in poor and rapidly growing rural areas, there may be enough TWWR-related benefits (conservation of resources, support for irrigated agriculture, etc.) to render the CBA purely incidental when making decisions with regards to implementing wastewater treatment systems (Choukr'Allah 2010).

Certain limitations and criticisms of the ABC methodology touch upon the use of environmental and social indicators that do not reflect the true impact on the environment or society. The methodologies used (contingent valuation approach, choice of experiment approach, etc.) can be time-consuming and difficult to implement.

ENVIRONMENAL ASSESSMENT TOOLS

Environmental assessment tools have been developed and used with the following main objectives:

- to ensure environmental sustainability;
- to divert hazardous impacts that may affect consumers;
- to minimize environmental damage.

The **water footprint** is a single-criterion analysis tool. It focuses on impacts on water resources by measuring the amount of water used to produce a service. The concept of virtual water is included here. The water footprint can also be used to quantify the water consumed by a given country or, globally, in a particular river basin or an aquifer.

Environmental impact assessments and risk management assessments are two of the environmental tools used in the preliminary stages of projects in the wastewater treatment and reuse sectors (Ahmed 2010).

The **Life Cycle Assessment** methodology has been adapted to wastewater treatment, as well as irrigation systems, but it seems that it has never (or rarely) been applied to a complete and integrated wastewater reuse chain.

Environmental Impact Assessment (EIA)

The EIA is a process for "identifying the likely consequences for the biogeophysical environment and for man's health and welfare of implementing particular activities and for conveying this information, at a stage when it can materially affect their decision, to those responsible for sanctioning the proposals" (Wathern 1988). The objective of the EIA is to ensure that environmental issues are anticipated and properly addressed by decision makers.

Environmental impact assessments have been implemented in many different forms around the world and using non-equivalent methods. EIAs have been widely used to set up wastewater treatment plants as a planning tool so as to predict the expected impacts, thereby providing possible alternatives and mitigation measures (Ahmed 2010). In developing countries, aid agencies often request EIAs for the treatment plant and reuse projects they fund.

However this methodology has certain restrictions that tend to limit its status as an environmental assessment tool. It is carried out over a given time, often late in the planning process, usually after the project managers have decided on a particular design. Therefore it is hardly to be expected that the EIA will propose significant changes to key decisions.

Risk assessment and management

Wastewater reuse carries a combination of health, environmental or agronomic risks. Risk assessment and management is a comprehensive process in which the available data are used to estimate the frequency of occurrence of hazards or specific events (probability) as well as the magnitude of their impacts (Condom 2012).

The risks and their impacts must be clearly identified, and then risk reduction measures are proposed. This method is considered as a decision-making tool used by managers and decision-makers to develop, analyse and compare the various options and select the appropriate response to a potential health hazard. An "acceptable" level of risk must be identified (Ahmed 2010). However, one limitation of the risk analysis is that if a product is converted into another substance already in use, it is not included in the assessment process.

Compared with the classic EIA, risk assessment and management includes and considers the uncertainties and risks during the project implementation and functioning. Risk assessment and management is now almost always included in the EIA.

Life Cycle Analysis (LCA)

The LCA methodology

The life cycle analysis makes decision-making easier and provides a rigorous assessment of the environmental sustainability of a product, service or process. It is currently considered as the most holistic environmental assessment tool. It takes all of the process-related upstream and downstream impacts into account. As a result, all environmental issues are gathered together in a quantitative methodology (Risch 2012). The LCA methodology also extends beyond this as it provides a basis for assessing the potential for improving the environmental performance of a system (Hellweg 2014).

The **simplified LCA** is used as an alternative to the detailed LCA **when the full spectrum of data required for a detailed LCA are not available**. It uses quantitative and/or qualitative generic sets of data. It also includes an estimation of the impacts over a simplified life cycle that focuses on specific life cycle stages where significant environmental impacts are identified. It is usually presented as a matrix: the life cycle stages are on one axis and the environmental impacts are on the other. It costs less and has shorter deadlines. However, this methodology still needs to be developed and standardized.

More recently, a lack of holistic methods has been identified (Loiseau 2012) for the environmental assessment of territorial-regional scenarios (including all production and consumption activities). On this basis, territorial LCAs have been developed (Loiseau 2013) as a very promising tool to promote the development of a circular economy.

LCA applied to water management and wastewater treatment

Within a context of growing awareness of climate change and water scarcity, urban water management faces many challenges related to water resources, water users and the associated technologies. Decision-makers need tools to assess

METHODOLOGY TOOLKIT - LIFE CYCLE ANALYSIS

Standards ISO 14040 and ISO 14044 address both the technical details and conceptual organization of the LCA.

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

- compiling an inventory of relevant inputs and outputs of a production system;
- evaluating the potential environmental impacts associated with those inputs and outputs;
- interpreting the results of the inventory analysis and impact assessment phases in relation to the objectives of the study" (ISO 14.040).

The LCA is global, quantitative and uses multiple criteria. It follows an iterative process between the results and interpretation.

STEP 1: Definition of the LCA goals: why does the LCA need to be carried out?

STEP 2: Description of the system's limitations (conceptual, geographic and temporal): the limitations must be defined based on the main objectives of the LCA and by integrating the receiving environment. They will have an influence on the data collection process. LCA limitations must be assessed and anticipated at the same time (data quality and main assumptions). The flow chart integrating all steps and components of the process is constructed.

STEP 3: Definition of an appropriate functional unit; the inputs and outputs are linked to this unit: it is a product or service whose environmental impacts will be assessed or compared. This definition is necessary to ensure that the results can be compared. It must be linked to the main questions/goals of the study.

STEP 4: Inventory: collection of data to quantify the inputs and outputs of the system (energy, raw materials, emissions and productions are calculated for the entire life cycle). The data collected are also linked to the process unit and functional unit.

STEP 5: Life Cycle Impact Assessment: identification of the effects and impacts on the environment by the system. The quality of the data collected in step 4 is paramount.

STEP 6: Quantification of the impacts and grouping into impact categories and intermediate effects (mid-points, in the middle of the causal chain): equivalence factors can be used to quantify the various impacts (e.g. phosphate equivalent for the impact of eutrophication, CO_2 equivalent for climate change, etc.). The impacts are first grouped into 18 independent impact categories (the environmental profile graph can be used to compare scenarios based on these 18 impact categories, including climate change, eutrophication, ecotoxicity, human toxicity, aquatic toxicity for freshwater and

seawater), and then into intermediate impact categories. They are then grouped into 3 endpoints (damage, at the end of the causal chain): human health (DALY), resources (in monetary terms), and biodiversity (as a percentage of the species affected).
Decision-makers and those not familiar with this methodology may find it difficult to draw solid results from environmental profiles.

STEP 7: Normalization is used to produce a reference framework. The unit in each impact category in the environmental profile are different due to the calculation processes. As a result, the values are related to the magnitude of the problem over a given period of time. For example, the total CO2 emissions for the process are related to a country's total CO2 emissions during the same period of time.

STEP 8: A sensitivity analysis is carried out on the results to test the robustness of the results in terms of the main uncertainties and assumptions (Wei 2015). At the same time as the sensitivity analysis, uncertainty can be assessed using Monte Carlo simulations on stochastic datasets from the inventory.

STEP 9: The goal of the value assignment step is to produce individual scores by weighting and clustering all the scores by impact category. This step makes it easier to make decisions, but is very controversial and subjective because it is anthropocentric and based on value judgements. This step is not mandatory.

STEP 10: Interpretation and presentation of the results: presentation of the critical sources of the impacts (key questions for decision making) and the options to reduce these impacts.

The goal of social LCAs is to quantify the social consequences of a product or production service throughout its life cycle. This socio-economic assessment can also be used to structure a dialogue with the various stakeholders. The LCA tool is currently at an early stage of development. Therefore, data and experience feedback are necessary to improve the methodology.

the environmental impacts of urban water systems and thereby compare technical solutions, including infrastructures, operation and maintenance. Holistic approaches are needed to evaluate all the components in the system in an integrated manner, and the life cycle analysis is being used more and more for this purpose within the water community (Loubet 2014).

For wastewater treatment systems in particular, the objective of the LCA is to assess whether or not the high-tech treatment technologies used to treat water (and thereby reduce the impact on the water resource at the outlet) are valid with respect to the energy, raw material, chemical consumption and emission related impacts. The complete treatment process cycle is analysed. Thus, LCA studies should be used to guide decision-making so as to avoid the implementation of infrastructures that do not meet human and environmental objectives in favour of clean technologies that include nutrient and water recycling and efficient resource reuse (Risch 2015). Certain recent studies have created new opportunities to better take potential reuse benefits into account: (i) Risch (2014) by assessing the highest consumption of water during wastewater treatment and (ii) Harder (2014) and Heimersson (2014) by including the pathogenic risk in the life cycle analysis of wastewater management and (iii) Loubet (2013) by assessing water loss at the watershed scale in a LCA that incorporates downstream cascade effects.

LCA for wastewater reuse in developing countries

Wastewater treatment projects are rarely subjected to a LCA and no information has been found in the literature regarding ongoing LCAs for wastewater reuse projects in developing countries. However, the LCA methodology is often well known because a LCA is required for many products that are exported to developed countries in order to be sold (product guarantee for environmental protection).

In the case of an assessment of the wastewater reuse chain:
- "Cradle-to-grave": "cradle" is equivalent to the production and collection of raw wastewater, whereas "grave" would be the total of all flows in the environment (receiving water bodies);
- The particular service could be "to irrigate 1 ha with treated wastewater", or "to cultivate 1 ha of irrigated crops with treated wastewater", compared with the use of conventional water resources;
- the by-products (or co-products) are the sludge produced during the treatment stages and agricultural productions.

The flow diagram represents the various and successive stages of the treated wastewater reuse chain. For each stage (treatment, storage, irrigation, etc.), inputs (raw materials, energy, etc.) and outputs (emissions into the air, water, soil and solid waste) are calculated and converted into environmental impacts, before being summed in order to obtain the overall impact of the life cycle of the product (or service) on both the environment and health.

Before initiating the LCA methodology, the objectives of the study must be correctly identified:
- The objective may be to compare two scenarios (2 scenarios for 2 alternative reuse technologies or 1 reuse scenario compared to a conventional treatment combined with conventional irrigation without reuse). It is then possible to remove the identical steps ("ceteris paribus"). For example, wastewater treatment plants that have already been built in a city (or will be in all cases) and policy makers looking to see if it is worthwhile (from an environmental point of view) to reuse water (by adding tertiary treatments, constructing irrigation networks, etc.); thus the primary and secondary treatment stages can be removed (in both scenarios);
- The objective may be to assess the environmental impact of irrigation with treated wastewater for eco-design purposes (improvement of the eco-efficiency of the system based on the identification of the main contributors to the impacts, at each stage of the life cycle). In this case, all stages of the reuse chain (starting from RWW collection) must be included and analysed in the flow chart.

The main problems with LCA application in developing countries are:
- The low level of awareness of the usefulness of such tools among decision-makers;
- Lack of capacity (software, unsuitable complex methodology);
- Lack of accessible contextual data;
- The need for adequate and appropriate impact categories;
- Lack of collaboration between the LCA experts in the region.

Research on the LCA for wastewater primarily involves developed countries with very limited contributions from developing countries. As a result, few databases exist. However data can also be collected from the literature, estimates, or mathematical modelling.

Another limitation of the LCA is that decision makers have a hard time assimilating, integrating and accessing the results given that it does not provide a single score for the environmental and health assessment.

The simplified LCA reflects the complexity and ambiguity of the LCA and provides an appropriate logistical framework for its application.

In developing countries faced with an increasing need for wastewater treatment plants and reuse systems, the use of the LCA can be a viable tool for sustainable decision-making. The LCA methodology should be vetted and appropriate for formulating environmental policies.

COMBINED USE OF DIFFERENT TOOLS FOR A CUSTOMIZED ASSESSMENT

The multicriteria and multidisciplinary approaches presented above address all the environmental issues, whereas the methodologies are adapted to achieve different objectives, from the local project scale to broader strategic considerations (e.g. city, region or watershed). Project managers must be aware of the specific characteristics of each tool and carefully set their goals before initiating studies.

Economy

The LCA and EIA both address environmental issues, however the economic component is hardly taken into account, which means that essential information is missing (Ahmed 2010). **The economic and financial cost/benefit analysis seems to be the most appropriate tool to assess economic considerations**. Although CBAs have been carried out since the middle of the 20th century, major challenges and limitations still exist with regards to the use of environmental indicators.

Environmental impacts

Environmental impact assessments and risk assessment and management are localized and site-specific approaches since the actual emissions and impacts on the local site-specific environment are assessed, whereas the LCA assesses broader potential impacts. The LCA is a limited methodology for assessing the real impact: for example, emissions and related impacts are quantified over a given period without taking the distribution over that period or its related specific impacts into account (Ahmed 2010). Conversely, compared with the LCA, the EIA tends to neglect indirect and cumulative impacts (Guinee 2001).

The **LCA** is linked to the mass and energy balance during normal operation, as the chain of effects are restricted to primary effects or potential effects, whereas accidental emissions or accidents, which are considered as vital to assessing and managing the risks, are not within the scope of the LCA (Ahmed 2010).

The results of the impact assessment using the LCA are expressed as common numerical indicators (for all impacts/emissions) which are usually independent of space and time, whereas the impacts of environmental impact assessments and risk assessment and management assessments are expressed as specific concentrations for a given context and project.

The specific characteristics of wastewater reuse projects

There are **no solutions that involve the use of one single tool**. Instead, a **complementary set of tools** that have been chosen and combined based on the context and goals are used to assess projects with regards to economic, environmental and social considerations.

First, decision-makers need to identify the wastewater reuse scenarios that they have on their territory.

When a project is about to start (the wastewater treatment plant has been chosen, there is only one reuse scenario), the most appropriate tools for the environmental assessment and risk assessment appear to be the EIA and risk assessment and management. Furthermore, treated wastewater reuse may have widespread socio-economic impacts, and (as discussed in Chapter 3) as well as broader impacts on the environment. As a result, integrative approaches and a process-based approach are required.

However, when decision-makers are required to think on a larger scale (region, basin or city level) and are involved in broader decisions and for broad guidelines, the LCA is an integrated tool that would be able to assess the environmental impact of different reuse scenarios.

An EIA is often mandatory for current wastewater reuse projects (required by the funders), whereas the LCA is often done on a voluntary basis.

There is little CBA and LCA experience feedback in developing countries, particularly on wastewater reuse. If other studies are carried out, more data and knowledge will be shared.

PROSPECTIVES FOR FUTURE DEVELOPMENTS

The economic aspect of a project is a major concern for decision makers and funders. Specific and accessible tools - and their associated databases - need to be developed to enable local technical engineering departments to conduct **private and social CBAs**.

LCA methodologies have already been developed to address wastewater treatment and irrigation projects. The LCA should be applied to wastewater reuse projects to demonstrate the potential for large-scale projects. The first steps are to collect the data needed for LCAs and to develop a methodological framework.

In addition, one of the keys to sustainable reuse projects is the identification of the best indicators and criteria that can be used to monitor process performance in reuse scenarios and to develop real-time (or near-real) monitoring techniques for their measurement.

MAIN RECOMMENDATIONS FOR FUTURE DEVELOPMENTS

This section summarizes the main recommendations for filling the gaps in knowledge, methodologies and operational practices.

Adopt an integrated framework

It is strongly recommended to include wastewater reuse in all integrated water resource management plans and to connect it with other economic sectors in order to accelerate cost recovery, risk reduction and sustainable implementation.

Specific regulations and organizational frameworks need to be developed to enable an **appropriate sharing of responsibilities** among the different, often many, project partners. Guidelines and policies must promote **standards based on local capacities and local reuse options**.

All stakeholders must be integrated into water reuse plans from the start. Tools to facilitate the uptake of innovation and social learning include multi-actor platforms to encourage dialogue and the development of participatory methods.

The options to consider include **mixed public/private and public/public solutions** for investment, service delivery, operation and maintenance.

Upgrade systems so that they are safer and controlled by choosing appropriate technologies

The health risks are too high in the case of uncontrolled and unmonitored raw wastewater reuse. It is inappropriate to counteract them (good practices and multi-barrier system put forward by the WHO in 2006) given the advantages RWWR provides in economic and agronomic terms.

There is growing interest in low-cost and low-maintenance treatment systems such as lagooning, wetlands, or soil-aquifer infiltration. However, more experience feedback (new pilot studies) on such systems is necessary. In fact, the most **cost-effective** solutions should be considered. The reduction of the levels of risk (pathogens and other pollutants) related to agronomic systems (soils and crops), as well as during water transport and storage, and through irrigation systems, needs to be better understood and characterized. As a result, research on treatment technologies (even low-cost technologies and decentralized technologies) should concentrate **on systems that can reduce pathogens while maintaining the agronomic potential of wastewater**.

The choice of treatment technologies must be based on the quality of the water required by the downstream uses, and therefore RWW reuse must be integrated as soon as the phases of reflection for the treatment systems.

Wastewater reuse systems in peri-urban areas are often centralized urban systems deployed over vast surface areas. However, the progress made in decentralized wastewater treatment technologies and systems may be particularly relevant in rapidly growing urban contexts where the installation of centralized collection and treatment facilities is not cost effective (CGIAR 2012).

Prepare a new generation of decision-makers and professionals

It is necessary to **train and raise the awareness** of decision-makers:

- at the national and regional scale for decision-makers, so as to give them the keys to identify areas with high potential and to create an appropriate organizational framework (regulation, sharing of responsibilities, etc.);
- at the local and project scale for local actors in charge of a reuse project, so as to provide them with a certified framework to carry out their project from the initial stage (idea) to a sustainable system.

For illustration purposes, it is often difficult for decision-makers and project managers to select the most appropriate technologies. They must be aware of all the possibilities and have all the key technical elements in hand in order to make the best choice based on their local conditions and constraints (economic, climatic, technical, etc.).

Assess the impacts on resources and develop decision-support tools

It would be interesting to apply **LCA methodologies** to specific sites so as to have a better overview of all the interactions and impacts between energy, water bodies and wastewater reuse.

Salinity is a key issue that is often undervalued in projects and regulations. Appropriate management of soil and water salinity must be implemented to mitigate the effects.

The economic component of the project is a major concern for decision-makers and funders. Specific and accessible tools - and the associated databases - need to be developed in order to allow local engineering technical departments to conduct **private and social CBAs** that take social equity into account when defining cost recovery mechanisms.

COUNTRY SUMMARIES

COUNTRY 1: TUNISIA
COUNTRY 2: MOROCCO
COUNTRY 3: JORDAN
COUNTRY 4: EGYPT
COUNTRY 5: THE PALESTINIAN TERRITORIES

COUNTRY 1: TUNISIA

Context

Tunisia has been developing TWW reuse for more than 30 years. The water treatment sector has undergone continuous developments which have enabled the installation of planned facilities. Approximately 24% of the treated wastewater is used for irrigation purposes in agriculture. More than anywhere else in the world, Tunisia has also taken steps to mitigate environmental and health risks associated with RWW use.

Remarkable experiences

Tunisia has successfully implemented treated wastewater reuse in several sectors:

- All golf courses in Tunisia are watered with TWW;
- More than 3.000 ha of crops and forests are irrigated with TWW (2009 figure);
- TWW is reused for environmental purposes such as wetland reclamation and groundwater recharge, implemented both in pilot studies and large-scale projects.

Main obstacles

Regulatory changes are expected. Irrigation with TWW is currently prohibited for high value-added crops such as vegetable crops, prompting farmers to return to more expensive conventional water resources.

Initially, WWTPs were not built near irrigated areas, making TWWR less attractive. Project managers are now trying to integrate the needs of the end-users when installing treatment equipment (Kampa 2010).

Future prospects

Work has already been carried out and is still ongoing to characterize and control the health, agronomic and environmental impacts (medium- and short-term impacts on plants, soils and groundwater by different pollutants, salinity, heavy metals and pathogens). Research work is now concentrating on levers that can be used to spread this practice (fresh water is still preferred, as higher value crops can be grown).

In addition to changes to the regulations, it is necessary to continue economic research on added value and pricing (comparison between TWW/conventional fresh water resources).

Experiences show that additional efforts must also be made to educate and involve local communities and wastewater end-users.

FOCUS: TWW salinity management in Sfax

In the city of Sfax, Tunisia, the wastewater treatment plant receives domestic and industrial effluents. The climate is arid with an annual rainfall of 200 mm. Two types of soils with different properties, sandy calcisol and clay fluvisol, were irrigated for 15 and 4 years respectively with treated wastewater. The electrical conductivity (EC) of the effluent varied between 4 and 7.7 dS/m (TDS between 3.56 and 5.13 g/L). Irrigation significantly increased salinization and sodification in both soil types studied. Irrigated calcisol is not sodic and is moderately salinized even if it has been irrigated for 15 years, whereas non-irrigated calcisol is not salinized at all. Irrigated fluvisol is sodic and salinized even though the control fluvisol (non-irrigated) is saline but not sodic. It seems that irrigation has had various impacts depending on the soil properties (primarily soil texture), irrigation protocol, and crop management. The EC of the surface layers decreases with salt leaching via additional treated wastewater and autumn-spring rains, and increases in the between-irrigation intervals during the harvest season due to rising salinized water through evaporation or root absorption (Kallel 2012).

COUTNRY 2: MOROCCO

Context

Morocco is lagging behind Tunisia in the field of TWWR, but is slowly moving towards bridging the gap with the construction of numerous wastewater treatment plants in medium-sized cities, most of which use lagoon systems. Nowadays, new WWTP construction projects often integrate TWWR in their objectives. The goal of this policy direction is to cope with the next water crisis and to restrict uncontrolled RWW reuse in peri-urban areas.

Remarkable experiences

In many large cities, TWW is already reused to water golf courses or green spaces. The medium-sized city of Settat, with 300 ha of corn, wheat and olive trees irrigated by TWW, is one of the best examples of TWWR in Morocco.

RWW reuse is still a common practice. In 2009, it was estimated that close to 70 mm^3 of RWW was used to irrigate a surface area of at least 7,200 ha on the outskirts of certain major cities (Marrakesh, Meknes, Oujda, Fez, etc.) downstream from effluent discharge points, or around treatment networks. It is prohibited in Morocco to use RWW to irrigate market garden crops for sale.

Main obstacles

Governments are unable to control RWW reuse and are also aware of the economic benefits it provides. Consumers are aware of this but are not ready to accept its legalization, even if controlled systems are in place. Morocco was recently confronted with serious health problems related to this practice.

Competition with unrestricted and the often free use of conventional water, combined with the limited effectiveness of WWTPs, have resulted in the failure of several TWWR projects, particularly in smaller communities.

The legal and regulatory framework for wastewater management is inconsistent and incomplete. It limits the coordination, regulation of tariffs, use and monitoring of discharges, penalties for non-compliance with standards and obligations (including industrial discharge) and the appropriate management of the associated sludge.

Future prospects

A new regulation project is being developed by the inter-ministerial group (Reval). TWWR is slowly emerging in Morocco as a major lever to control water shortages. Despite organizational and financial constraints, the government is trying to encourage and promote centralized and decentralized TWWR projects (small-scale systems in rural areas).

COUNTRY 3: JORDAN

Context

In Jordan, a country with a high water deficit, TWWR has long been a fully integrated component of long-term water resource management. TWWR is an alternative to water desalinization and very expensive water transfers.

Remarkable experiences

Jordan reuses up to 85% of the TWW. All treated wastewater collected from the two main cities (Amman and Zarqa) is mixed with freshwater (King Talal Dam) and used for unrestricted irrigation in the Jordan Valley.

TWWR irrigation near Amman in Jordan – Ecofilae © Condom

Main obstacles

The overexploitation of wastewater treatment plants results in the production of low-quality TWW. When wastewater is not diluted, it can only be legally used for restricted irrigation: however, there are numerous illegal withdrawals on the network between the treatment plant and the reservoirs where they are diluted.

Future prospects

Guidelines must be efficiently converted into standards, monitoring programs must be implemented, and the recommended threshold values must be applied.

One of the major challenges is the rehabilitation of WWTPs and TWWR options need to be examined and included in each new project. The fate of water co-products (such as sludge) must be anticipated before any new construction. No chains have been anticipated for sludge from the As-Samra WWTP (Amman). The reclamation of salinized environments must also be considered as a potential use of treated wastewater.

Experiences in Jordan reveal that interventions within the legal framework must be supplemented by campaigns to raise awareness. The general public must also form part of the TWWR process to ensure acceptability and to limit the unplanned use of wastewater.

COUNTRY 4: EGYPT

Context

The context is characterized by limited water resources (Falkenmark Water Stress Indicator close to 650 m^3/year/inhab.) and high agricultural water needs. It would be difficult to further mobilize conventional water resources (the Nile and groundwater).

The Nile and its delta receive all types of water discharge: treated and untreated domestic water, industrial effluents, which cause severe water pollution (Figure 21).

Agricultural drainage water and wastewater, diluted in the "fresh" water of the Nile, have been intensively, and for a long time now, reused downstream for several purposes, including crop irrigation.

In the Nile Delta, a surface area of 200,000 ha is cultivated, the volume of drinking water produced is approximately 1 mm^3/year, and the volume of TWW is 0.241 mm^3/year.

Remarkable experiences

Wastewater reuse is an ancient practice in Egypt. Since 1930, domestic wastewater has been reused on sandy soils in areas such as Al Gabal Al Asfar and Abu Rawash.

Starting in the 1990s, Egypt decided to recycle TWW to water planted forests (Figure 21). Pilot high forest plantations were established on 10 governorates covering all agricultural climatic zones. Egypt is one of the first countries to have developed public-private TWWR partnerships for these projects. As a result, TWWR is used on forest plantations in the desert, but never to irrigate other crops, for example market gardens and field crops.

Along the Nile and in the delta, the reuse of drainage waters is now planned and partly controlled. However the unplanned and uncontrolled reuse practices that are still commonly used by farmers carry significant health risks; farmers have few other options.

Crop rotations are adapted depending on the quality of the water: from upstream to downstream, rice, wheat and maize have been replaced with aquaculture.

Small-scale reuse systems for greywater or bayaras (septic tanks) are also being developed in rural areas where it is not planned to expand the coverage of the water treatment systems and treatment plants for the next few decades to come.

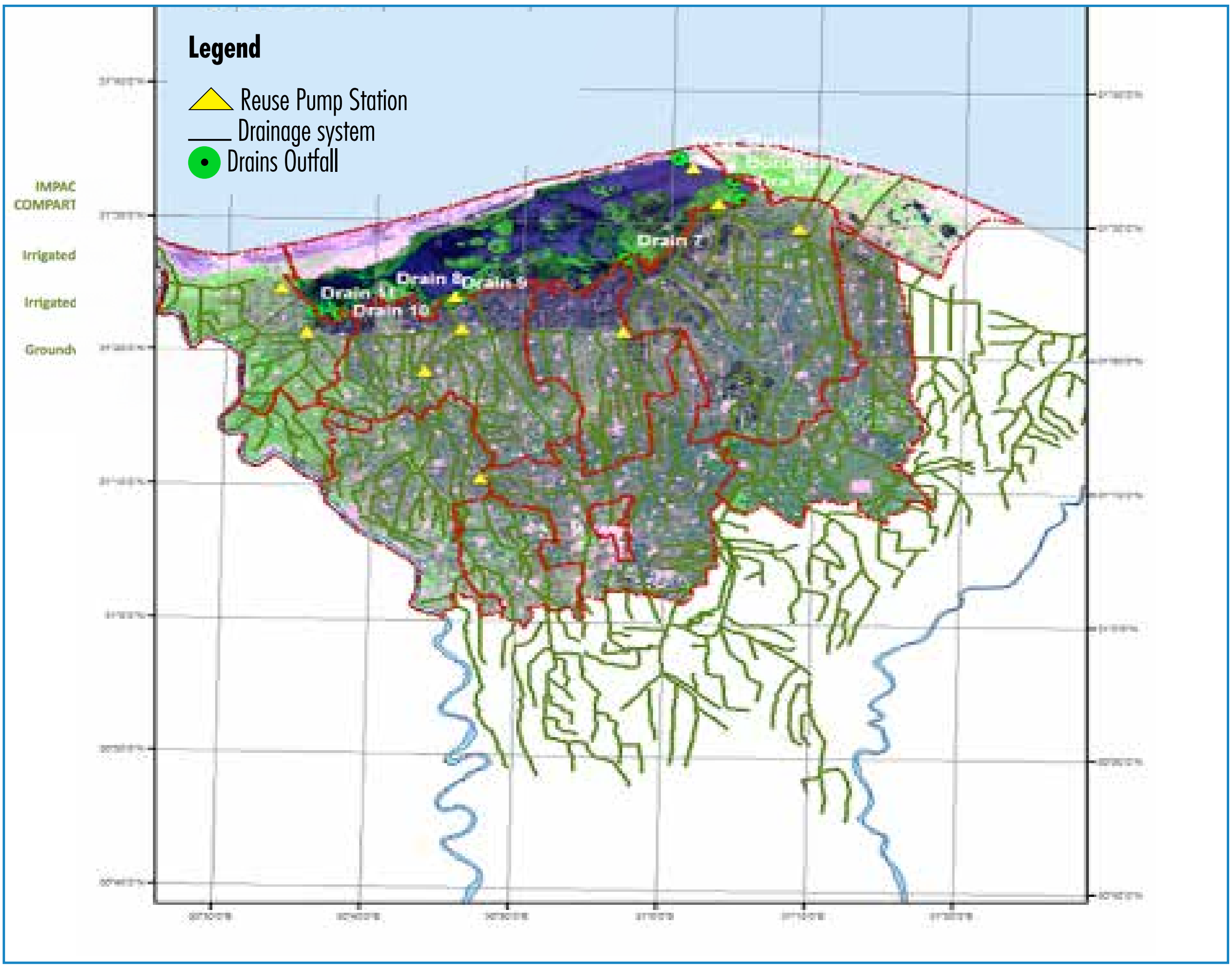


FIGURE 20: Drainage and reuse systems in the Nile Delta – Farag ICID 2015

Main obstacles

At the moment, regulations and standards are very restrictive: treated wastewater reuse is limited to the irrigation of tree plantations. Usage restrictions, as well as the low cost of using water from the Nile and groundwater resources do not provide incentives for investments in wastewater reuse. However, compliance with and the application of standards are very low, because they are not affordable for the country.

Several Ministries and authorities are involved in treated wastewater reuse projects and there is a lack coordination and communication.

Future prospects

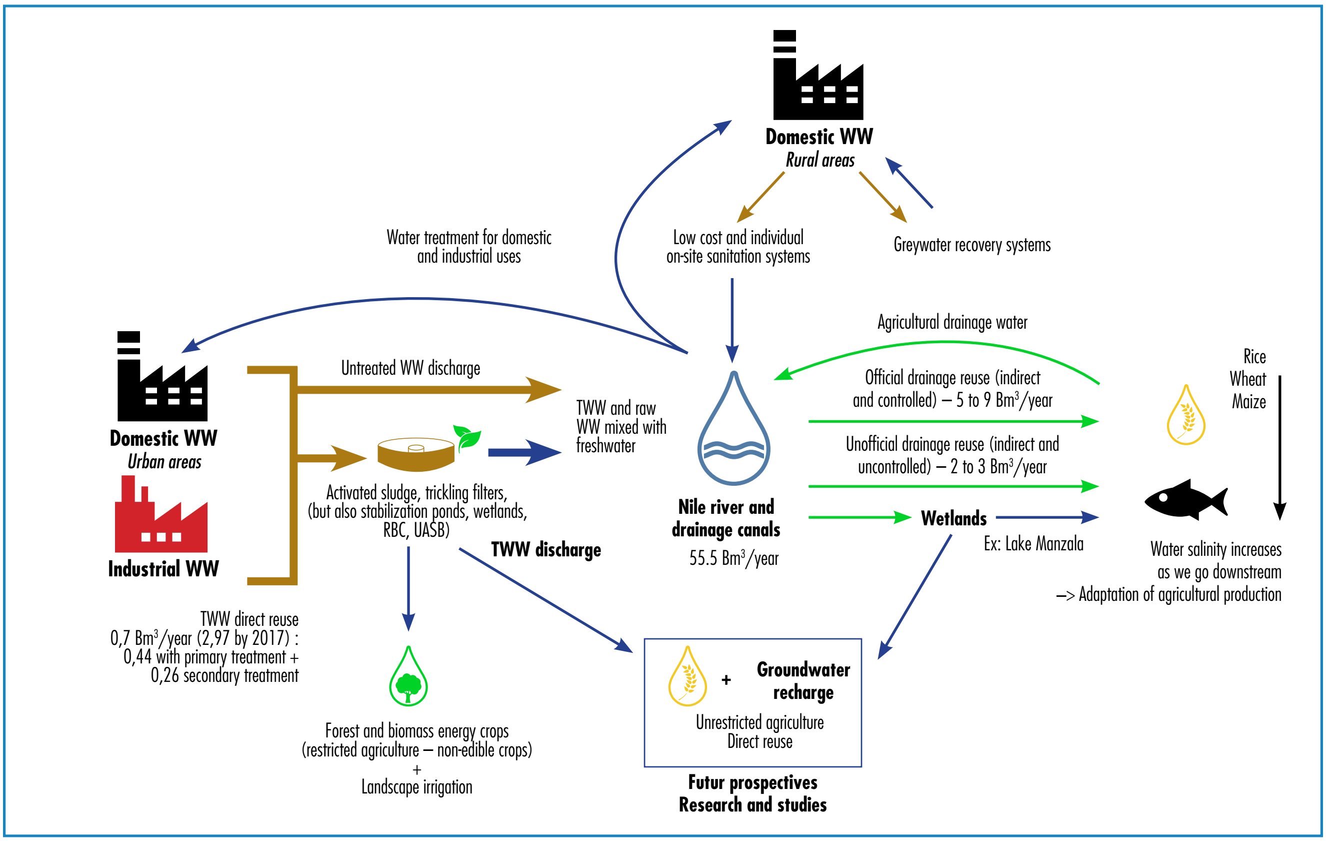
The next revision of the legislation must include the irrigation of food crops and groundwater recharge.

There are no centralized treatment systems planned in rural areas. Small-scale, low-cost decentralized systems related to TWWR must be established.

Economic assessment methods are also required because a full cost-benefit analysis has never been carried out on TWWR in Egypt: the total value of TWW has not yet been fully exploited.

Work is also needed to monitor the quality of treated wastewater and to raise public awareness as health fears are a major obstacle for continuing the expansion of TWWR.

FIGURE 21: Block diagram of wastewater flows and reuse in Egypt - Ecofilae diagram



COUNTRY 5: THE PALESTINIAN TERRITORIES

Context

The Palestinian Territories (Gaza Strip and the West Bank) are faced with severe constraints regarding water resources, both in terms of quality and scarcity: there is virtually no surface water, the Wadi Gaza is deviated before reaching the Gaza Strip, and the coastal aquifer (Gaza) is overexploited, salty and polluted. Furthermore, the population is growing and the treatment plants are overloaded.

However, the wastewater generated (56 mm^3/year in Gaza) potentially corresponds to 70% of the irrigation water demand in Gaza.

Remarkable experiences

There are still few water reuse experiences in Palestine. The villages of Anza and Beit Dajan in the West Bank produce crops through safe and sustainable wastewater reuse.

At the Sheikh Ajleen wastewater treatment plant (Gaza Strip), partially treated wastewater is reused to irrigate citrus, olive and palm plantations. The economic returns are very high for farmers (savings in nutrient inputs, better yields).

NGOs have also installed small-scale reuse systems.

Main obstacles

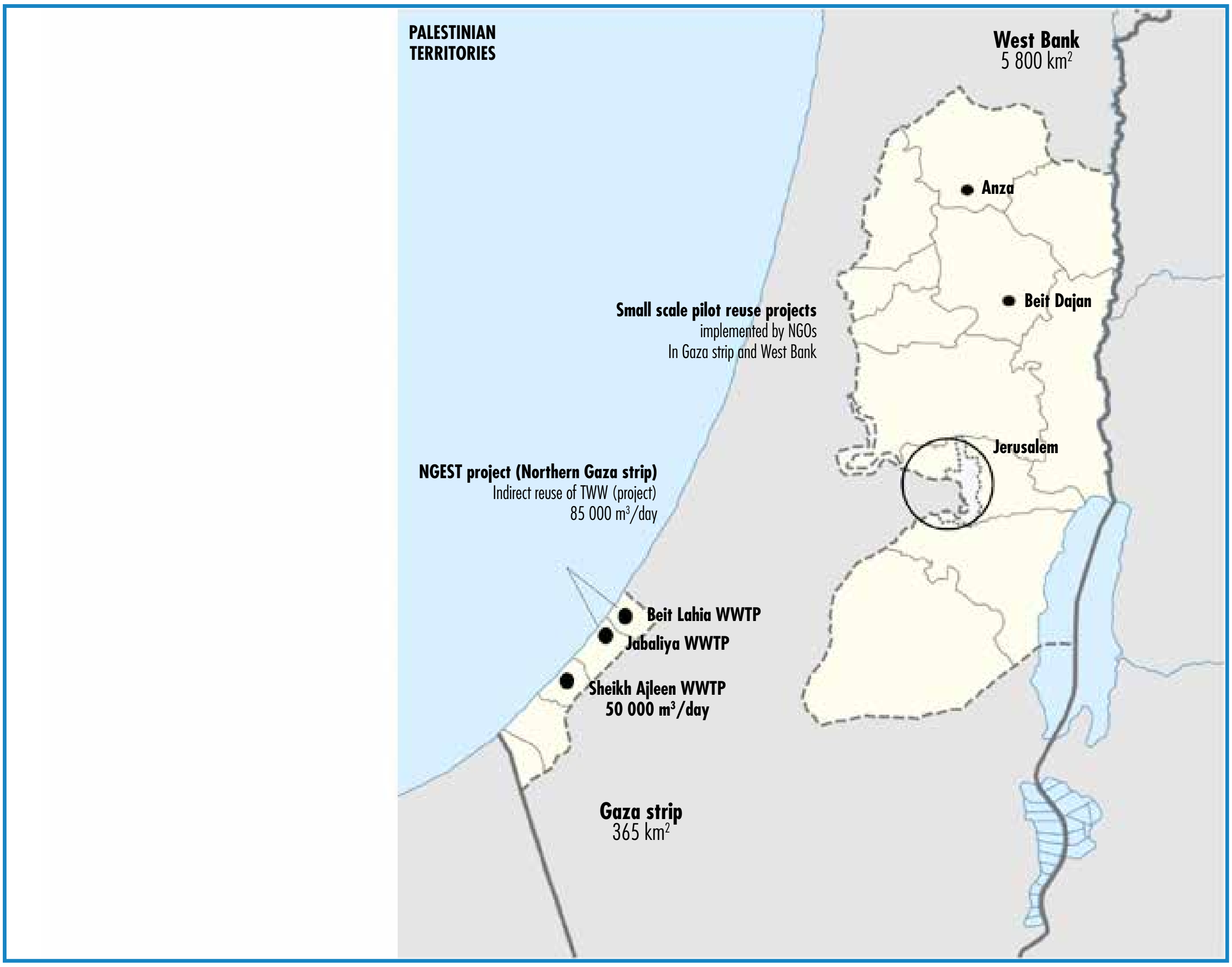
The regulatory framework is very recent but the irrigation of vegetable crops with treated wastewater is still prohibited.

In addition to the complex political context, the limiting factors are coordination and communication among the multiple bodies of the Palestinian Water Authority.

Future prospects

The NGEST project implemented in the Gaza Strip (Project 9) is considered by far as the largest TWWR project in Palestine.

FIGURE 22: TWWR projects in the Palestinian Territories - Ecofilae diagram



PROJECT SUMMARIES

PROJECT 1
Experience of the city of Accra in Ghana (Drechsel 2014)

The difficulty of implementing and efficiently operating reclamation infrastructures

In Ghana, only a small part of faecal sludge and wastewater is actually treated and less than 5% of the population is connected to a reclamation system. According to the IWMI, in 2013, more than 50% of WWTPs were non-functional, and more than 25% were partially functional.

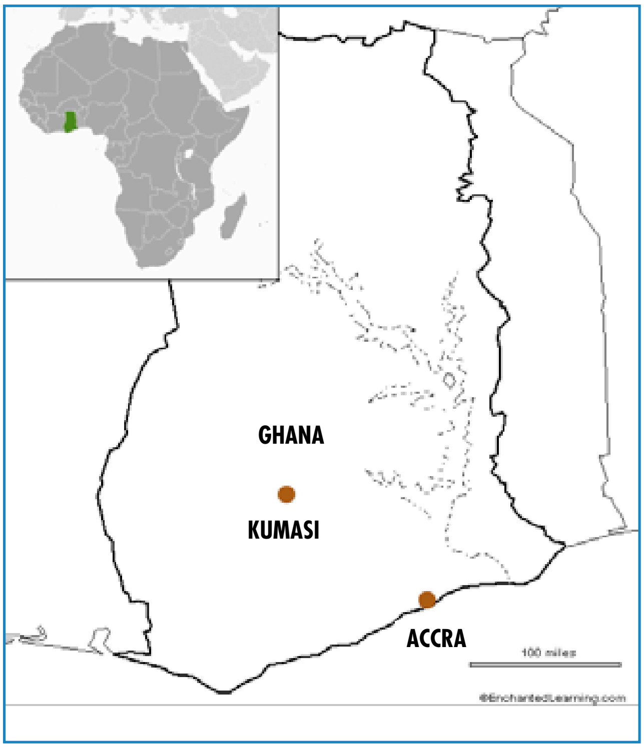


FIGURE 23: Accra and Kumasi in Ghana

Raw wastewater recovery: a common practise

In Ghana, most of the water resources mobilized for irrigation are contaminated with untreated domestic wastewater due to inadequate urban treatment. The IWMI (not published) estimated that in Ghana, a surface area of 40,000 ha around cities and villages is irrigated seasonally using RWW. This is equivalent to several times the total surface area of the country which currently uses formal irrigation.

For the city of Accra (estimated population of roughly 2.5 million people), the main sources of irrigation water are storm water drains and polluted streams. The water from these natural or man-made drains contains either RWW, rainwater or water, the dilution of which depends on the places and the seasons. Some farmers also use raw wastewater from perforated sewer lines or partially treated effluents, in lagoons of dysfunctional wastewater treatment systems.

The Odaw River in Ghana, a worrisome environmental disaster that converges with the Korle Lagoon before reaching the ocean – IWMI

Water derived from drains for agricultural irrigation in Accra (Ghana) – Photograph: Mary Lydecker

Agricultural practices and irrigation practices

In Accra, including the Ashaiman and Tema Districts, there are approximately 800 to 1,000 market gardeners, 60% of whom produce exotic vegetables (lettuce, cabbage, spring onions, cauliflower, etc.) and 40% of whom produce traditional and native vegetables (tomatoes, okra, jute leaves (Corchorus olitorius), aubergines, and hot peppers).

On average, the size of the plots grown in the city is approximately 0.01 to 0.02 ha per farmer, with a maximum of 2 ha in peri-urban areas. The most common way to manually bring water to the plot from nearby resources is by using a watering can, however buckets or small motorized pumps may also be used. Gravity-fed irrigation, using furrows, is practised in Accra, whereas drip irrigation and sprinkler systems are rarely used.

Health risks related to contamination with pathogens

In Ghana, and more widely in the sub-region, the major health problem involves faecal-oral type diseases transmitted by pathogens. The Disability Adjusted Life Years (DALY), also called the morbidity burden, is estimated to be 0.017 per person per year in Ghana in urban areas, due to diarrhoea caused by water and reclamation problems (Seidu 2011) whereas the WHO recommends a value of less than 10^{-6} DALY.

Health and environmental problems associated with heavy metals and industrial chemical waste

In Ghana, and more broadly in the sub-region, there is a relatively low flow of industrial effluents into urban and peri-urban watercourses as the main industries are primarily found along the coast. However, tanneries, gold mines or vehicle repair sites have been identified as sources of pollution for RWW and streams by heavy metals.

Agronomic benefits of raw wastewater reuse

Close to 70% of urban Ghanaian farmers have reported that they had been cultivating their plots continuously for more than 10 to 20 years. This result is remarkable for a tropical context which, normally, only works using crop rotations. Nevertheless, the contribution of RWW in terms of nutrient inputs is lower when this wastewater is diluted. Erni et al. (2010) estimated that the nitrogen and phosphorus inputs via wastewater (2010) was approximately 10% lower than what is supplied by fertilizers, along the Oda River, which absorbs and dilutes most of the wastewater produced at Kumasi.

Farmers able to tap into RWW (in Accra, Tamale) and who have experimented with their nutritional value, try to take this into account in soil fertility management. However, most farmers use diluted wastewater or water from polluted streams with nutrient levels that are too low to be able to benefit from them and integrate them into their crop fertilization programs. Nutrient concentrations vary with the dilution, distance to the wastewater source, over time and between seasons, so it is almost impossible for farmers (who cannot afford laboratories) to predict the level of nutrients.

An entire local and subsistence economy depends on this resource

In Ghana, urban and peri-urban agriculture is a profitable activity with very high production rates. However, farmers are often forced to turn to other production sites when their plots are taken for construction. Approximately 2,000 urban farmers, 5,300 street vendors, and 800,000 daily consumers in large cities, as well as an unknown number of merchants benefit from peri-urban and urban agriculture. In Kumasi (another city in Ghana), the demand for vegetables (lettuce, scallions, etc.), as for fresh milk, is almost entirely covered by intra-urban production. Tomatoes, eggplants and cassava, as well as eggs and poultry, are produced in the peri-urban area, while basic products such as taro, plantain, maize and rice come from rural areas or are imported.

PROJECT 2
The reuse chain in Faisalabad (Pakistan)

Context and project objectives
Water is a scarce resource in the peri-urban area of Faisalabad and RWW is reused for irrigation on more than 2,500 ha.

Actors, operators and funders
The WASA (Water and Sanitation Agency) is in charge of the TWWR project.

Technical chain
TWW from the Faisalabad treatment lagoons are no longer used by farmers in the peri-urban area. Farmers have gone back to using RWW because it provides more agronomic and economic benefits. The reuse chains (abandoned TWWR and current RWWR) are described in Figure 24 below.

Obstacles encountered and solutions implemented
The failure of the TWWR project can be explained by technical problems related to the operation of the lagoons.

The ponds do not function in an efficient manner and therefore the performances are very limited. Extreme climatic conditions were not properly taken into account during the design: the evaporation rates are higher than 10 mm/day and the treated wastewater is too concentrated and saline for direct reuse by farmers.

Furthermore, the direct use of RWW by farmers exacerbates the malfunctioning of the WWTP: the amount of RWW input is too low, resulting in a doubled hydraulic retention time in the ponds.

Ponds have created favourable breeding conditions for mosquitoes (disease vector) due to the absence of a grid that was added later on in the preliminary treatment.

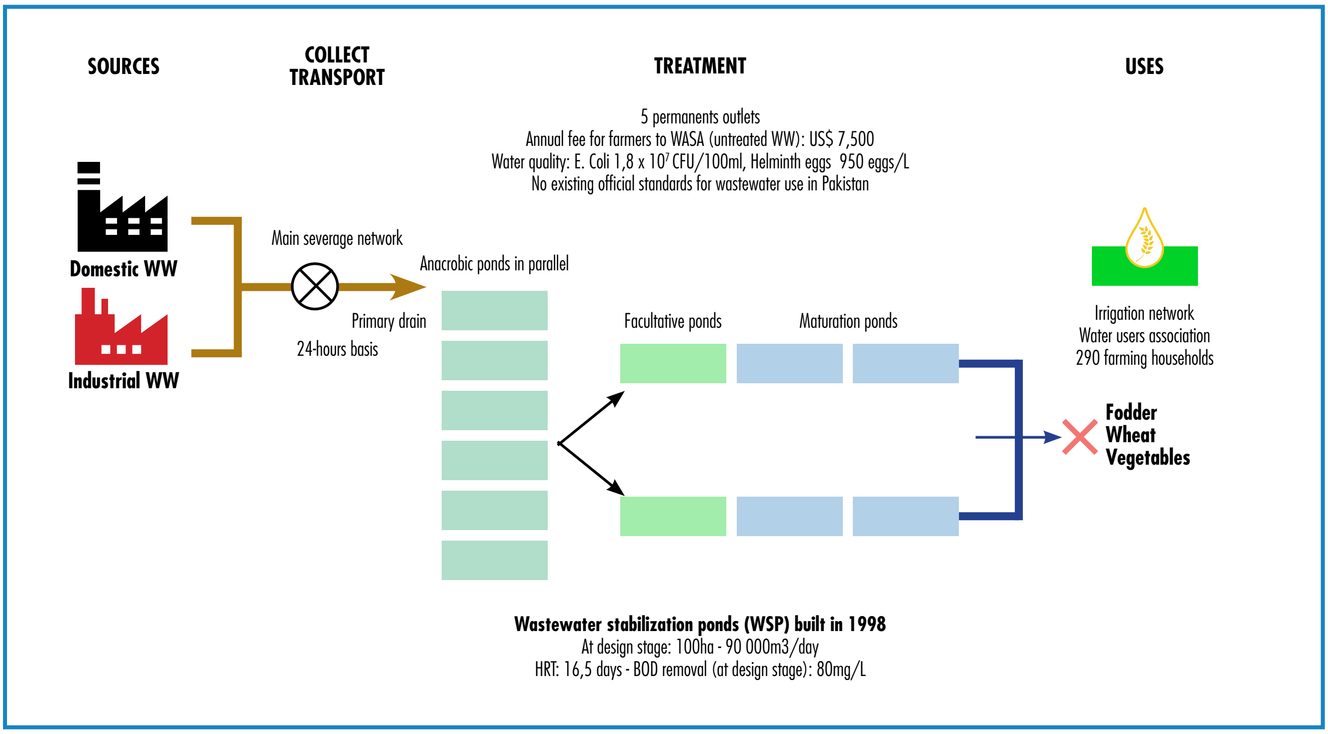
TWW in the ponds is considered to be too saline by farmers and has lower nitrogen concentrations than RWW (confirmed by a 1-year study).

On average, a farmer who uses RWW derives an income of $600/ha, which is much higher than for a farmer who uses conventional water for irrigation. Farmers using RWW cultivate higher value-added crops (primarily vegetables) with higher cropping intensity and do not apply fertilizers other than those supplied by RWW. In the city, vegetables irrigated with RWW are sold for almost 2 times less than those irrigated with conventional water.

In addition, land irrigated with RWW is 2.5 times more expensive than other close-by irrigated land (better fertility).

Health Risks
Health studies were carried out in the agricultural area irrigated with RWW. They indicated a low prevalence of intestinal nematode infections and no high heavy metal levels in the soils and agricultural products.

FIGURE 24: The reuse chain in Faisalabad (Pakistan) - Ecofilae diagram



PROJECT 3
The reuse chain in the Thanh Tri District in Hanoi (Vietnam)

Context and project objectives

Water shortages and uncontrolled raw wastewater reuse in the peri-urban area of Hanoi are the main drivers of the project. The objective is of the project is to move towards safer and more productive practices.

Actors, operators and funders

The Than Liet Agricultural Cooperative operates the water supply, treatment, drainage and irrigation system. Farmers are directly involved in the operation and maintenance.

Technical chain

Aerated lagoons are used to treat wastewater. A Low level of treatment combined with dilution and health protection control measures ensure safe wastewater reuse for the irrigation of rice, vegetables and for aquaculture production.

The reuse chain is described in Figure 25 below.

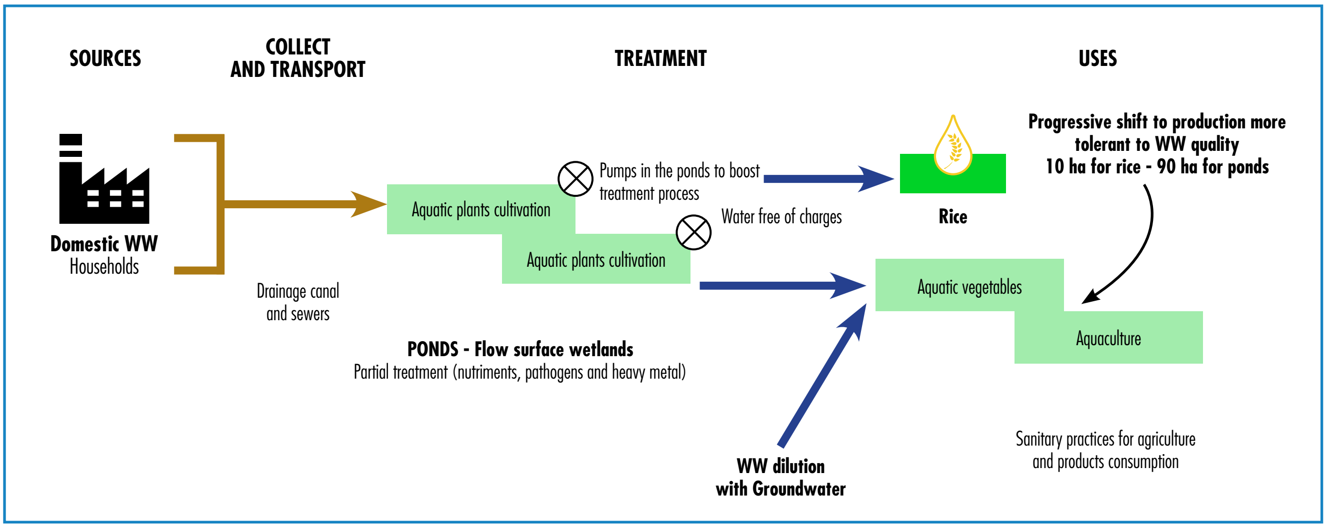
Obstacles encountered and solutions implemented

Agricultural production and the choice of crops are gradually moving towards more tolerant uses of wastewater: there are fewer rice fields in order to make way for aquaculture and aquatic vegetables.

There is a low level of treatment, and the risks of contamination are still high. Health protection control measures have been implemented to protect farmers and consumers (gloves and boots for the farmers, the cooking of vegetables, etc.).

Cultivated aquatic plants in Hanoi – Source: Jordan and Marisa Magnuson

FIGURE 25: The reuse chain in the Hanoi District (Vietnam) - Ecofilae diagram



PROJECT 4
The reuse chain in Settat (Morocco)

(Literature, supplemented with Pierre Louis Mayaux's intervention, CIRAD, during the ICID 2015)

Context and project objectives

RWW has been widely used in the area for a long time now, and as a result, TWWR was started de facto after the installation of the wastewater treatment plant. It was globally well accepted and tolerated. As a result, TWWR was spontaneously developed based on pre-existing social arrangements.

The main advantages of the project are the preservation of threatened groundwater resources (pollution and overexploitation), in addition to the limitation of RWWR (health objectives) in the peri-urban area.

Actors, operators and funders

There are many stakeholders and operators involved in the project, and the tasks and responsibilities are shared as follows:

- RADEEC (Autonomous Control of Water and Electricity Supply in Chaouia) is in charge of the wastewater treatment plant;
- ONSSA (National Office of Food Safety) checks the quality of agricultural production;
- the AUEA (Association of Agricultural Water Users) is in charge of irrigation infrastructures.

Historically, relationships have been good between local government agents and farmers The EIB (European Investment Bank) has granted a loan of €8 million for the project.

Technical chain

The TWWR technical chain is described in Figure 26.

Treated wastewater is used (4.2 m^3/year), after treatment in a lagoon, to irrigate 300 ha of public land (wheat, maize, berseem, potatoes, olive trees, etc.) in the peri-urban area of Settat. The initial investment for the network and irrigation systems was approximately €3 million. The annual costs for irrigation are estimated to be €67,000 per year.

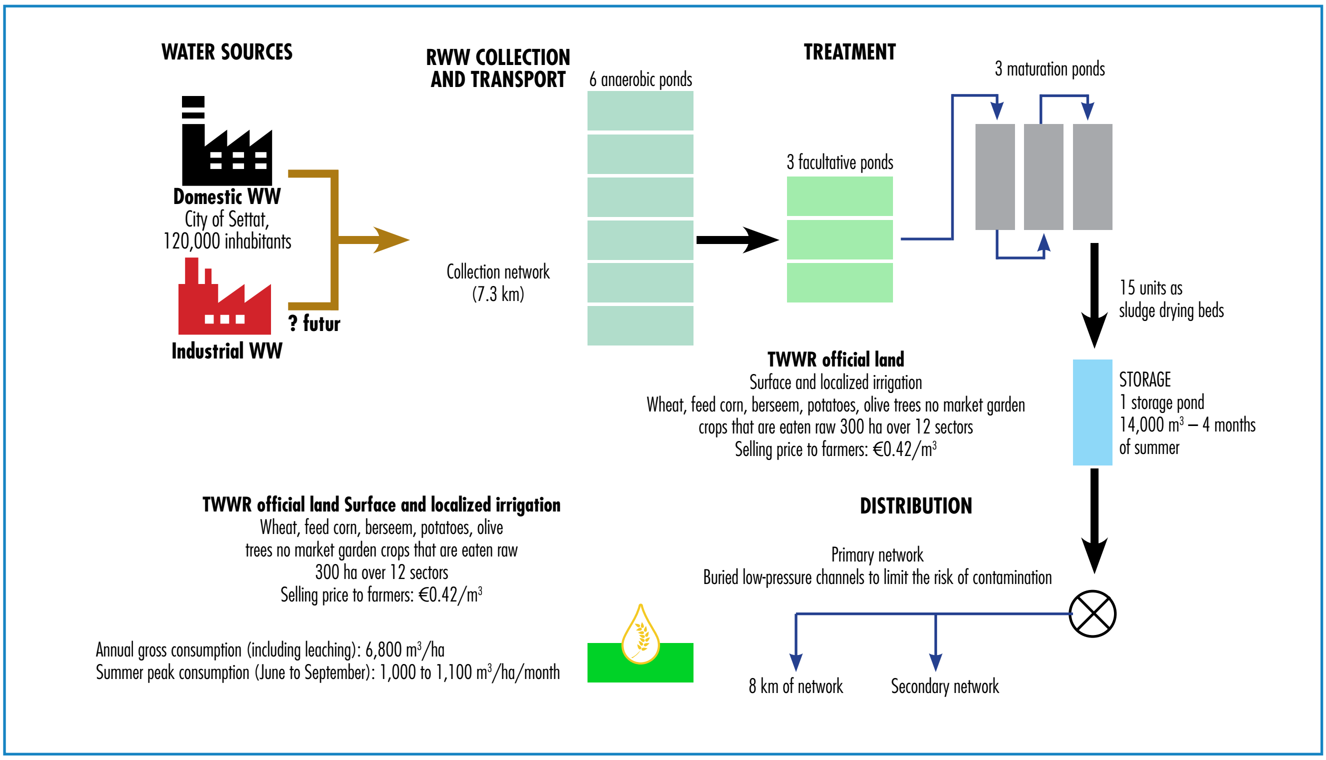
The cost of water is €0.42/m^3 for the farmers.

Obstacles encountered and solutions implemented

The project was successfully developed, despite the fact that institutional and legal frameworks in Morocco are still incomplete and a large number of actors need to be coordinated.
The salinity of treated wastewater is a major concern. This risk could be magnified if industrial wastewater is integrated into the collection network.

Settat treatment lagoons (Morocco) – Mayaux ICID 2015

FIGURE 26: The reuse chain in Settat, Morocco - Ecofilae diagram



PROJECT 5
The reuse chain in Ouagadougou (Burkina Faso)

Context and project objectives

The main objectives of the project were to:

- restrict RWWR in the peri-urban area within a context of rapid and uncontrolled urbanization;
- control TWWR.

Actors, operators and funders

The National Office for Water and Sanitation (ONEA) is in charge of the project management.

The initial investment into the wastewater treatment plant (€9.85 M) was provided by the French Development Agency (AFD) (71.1%), the World Bank (8.1%) and ONEA (8.6%).

Technical chain

The TWWR technical chain is described in Figure 27.

Domestic and industrial wastewater is treated in a lagoon system (appropriate for the local climate context), including maturation lagoons. TWW is then introduced into the irrigation network via gravity. Public land (restricted irrigation) and non-public land (crop rotation is not compulsory) are irrigated with treated wastewater supplied to farmers for free.

Obstacles encountered and solutions implemented

Given that industrial wastewater is present in the network, high levels of salinity have been observed in the TWW. Pre-treatment at industrial sites has been implemented. However, irrigated soils are still being affected by the salinity of the TWW.

ONEA had trouble maintaining the financial equilibrium. Sanitation taxes were adjusted with the operating costs.

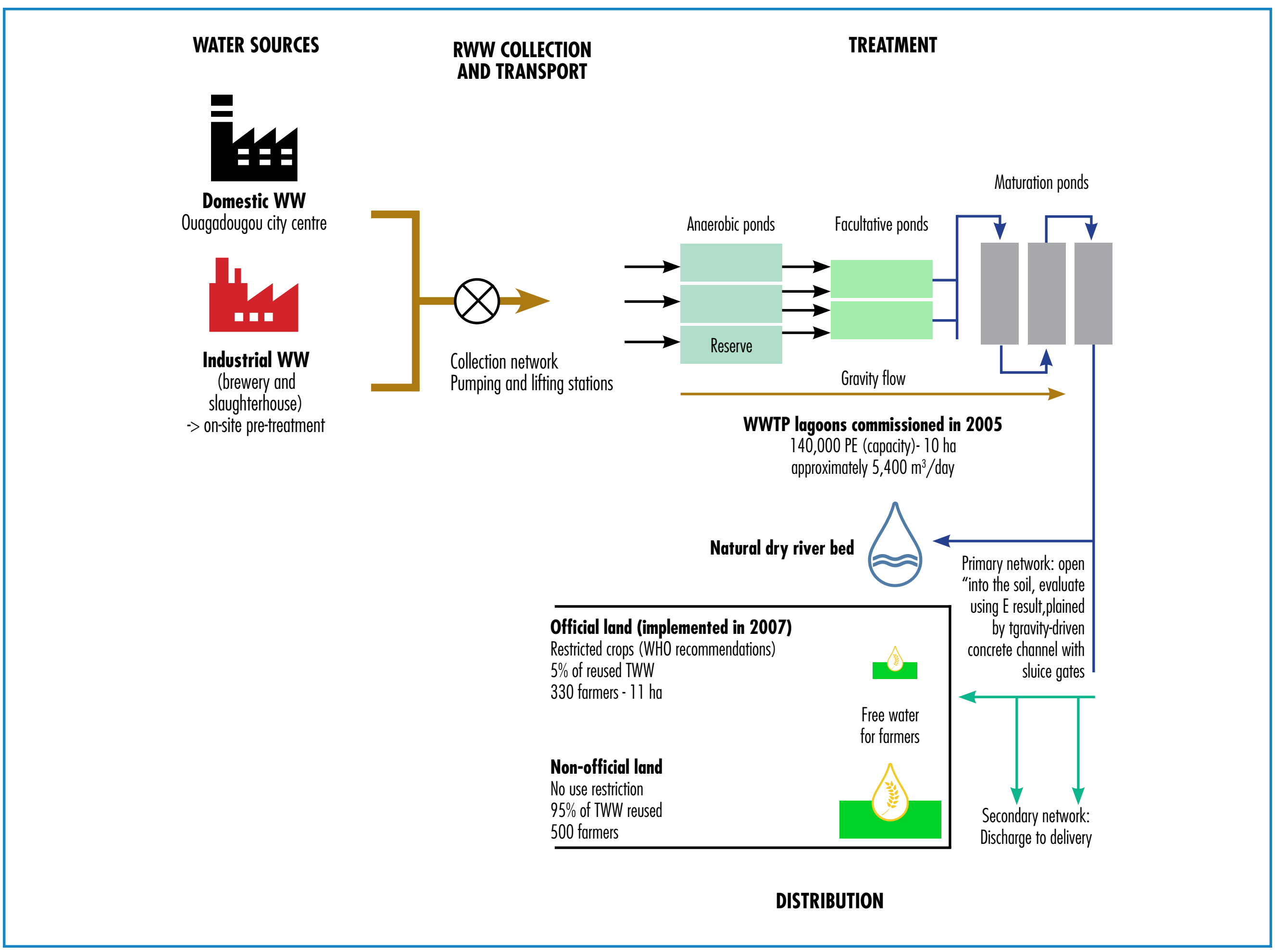
Acts of vandalism have been reported and few inspections are being carried out on the irrigation network.

High risks of landslides, erosion and flooding have been reported on agricultural land.

Farmers lack technical and financial capacities.

Public land is not competitive due to restricted irrigation and land fragmentation.

FIGURE 27: The reuse chain in Ouagadougou - Ecofilae diagram



PROJECT 6
The reuse chain in Okhla, Delhi (India)

Context and project objectives

Within an urban context with major water shortages, the main objective of the project is to provide more water for different uses in Delhi.

Actors, operators and funders

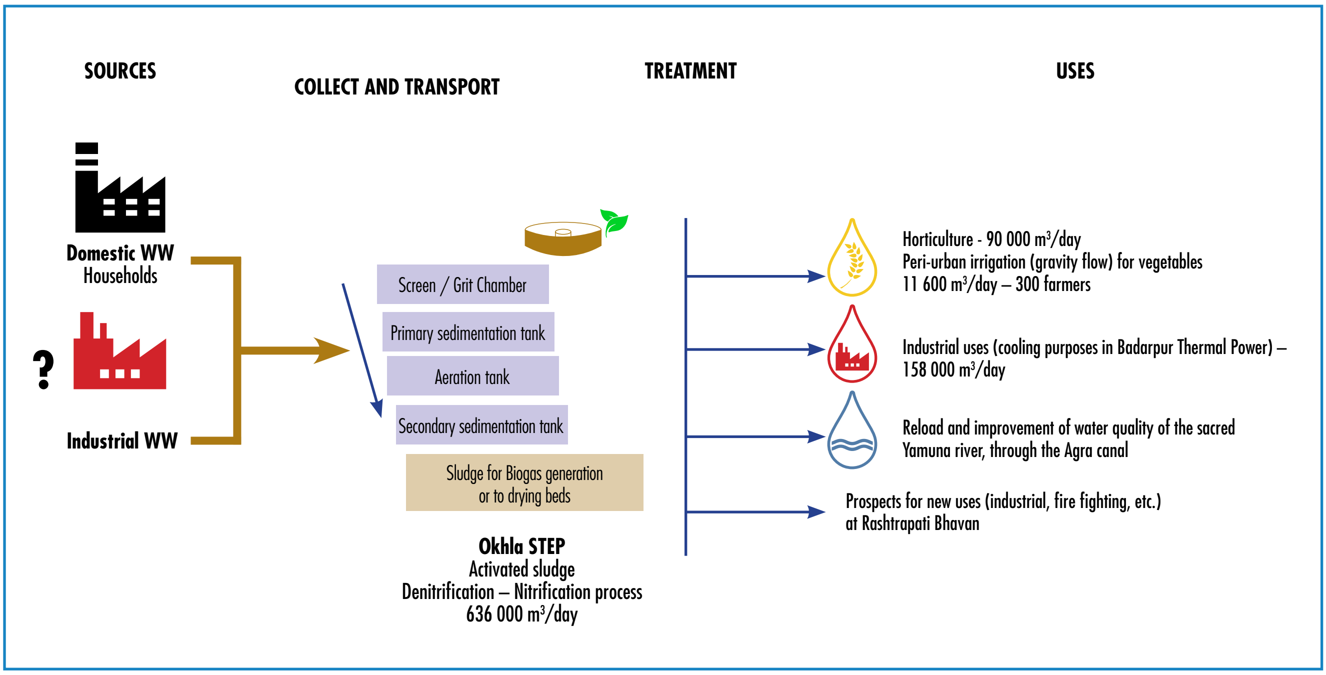
The project was supported by USAID. The Delhi Jal Board is responsible for the WWTP and the distribution of TWW.

Technical chain

The reuse chain is described in Figure 28 below.

Treated wastewater in the activated sludge system is sold for various uses: agriculture (37 mm^3/year) and industrial cooling (58 mm^3/year). The Delhi Jal Board is exploring new uses. TWW is also used to recharge and improve the quality of the water in the Yamuna River.

FIGURE 28: The reuse chain in Okhla, Delhi (India) - Ecofilae diagram



PROJECT 7
Experience in Dakar and elsewhere in Senegal

The supply of food and employment in the Dakar region (nearly 2.5 million inhabitants in total) depend on urban and peri-urban agriculture, which are in turn dependent on the water supply. Only rarely are quality freshwater resources and groundwater at high risk of salinization and contamination from uncontrolled wastewater discharge. Although prohibited, untreated wastewater discharge on agricultural land is a common practice.

In the **Pikine** neighbourhood of **Dakar**, approximately 16 ha have been irrigated with RWW for years. The 160 farmers reuse almost 2 mm^3 of wastewater per year (3% of the annual production of wastewater in Dakar) to irrigate vegetables (lettuce). Farmers divert wastewater from collection pipelines using hoses, to supply small wells located on their plots. They then use tin cans to water the field. Nevertheless, there are fewer RWWR practices due to upgrades to and the expansion of the city's sanitation system. TWW from the recent wastewater treatment plant in Pikine are now being reused for irrigation and as a means of restricting soil and groundwater salinization processes in the region.

In the Camberène neighbourhood of Dakar, ONAS (National Office of Urban Sanitation in Senegal) and the farmers' union plan to transfer and reuse TWW in the Niayes Valley, primarily for the production of horticultural products. This project is financed by the FAO and the Spanish Cooperation Programme. ONAS is committed to providing treated wastewater at a price not exceeding 50 CFAF/m^3 after tertiary treatment and 20 CFAF/m^3 after secondary treatment.

Treated wastewater from the cities of Thiès and Saly-Mbour is reused for the production of agricultural products. Few data are available for these two projects, located close to Dakar.

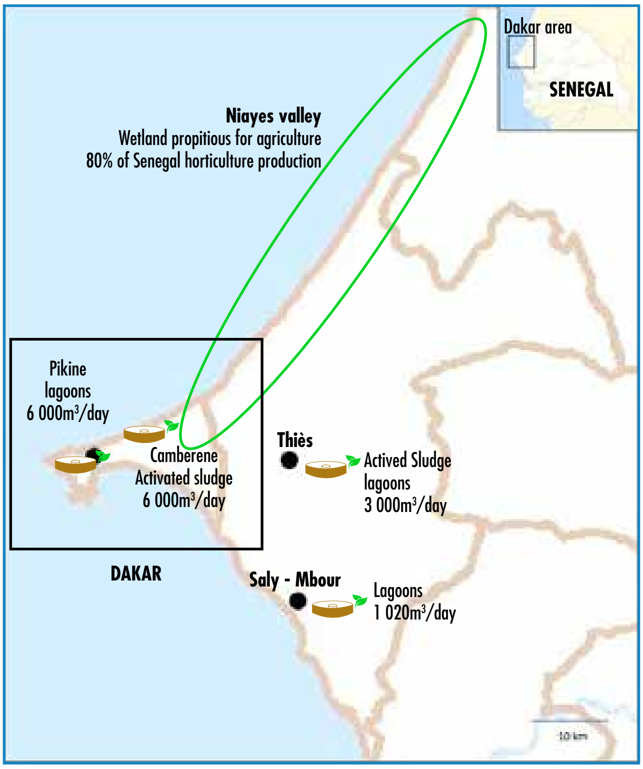


FIGURE 29: Location of the reuse experiences in Senegal - Ecofilae diagram

PROJECT 8
The reuse chain in Korba (Tunisia)

Context and project objectives

Freshwater resources are rare and valuable in the Korba region of Tunisia. Groundwater is overexploited (by agriculture) and there are definite risks of pollution and salinization. The main objectives of the project are to:

- recharge the groundwater and thereby restrict its overexploitation;
- provide good quality water to farmers;
- protect the environment: the coast, groundwater, lagoons (sabkha).

Actors, operators and funders

The project was financed by the Tunisian government (100%) in 2002. ONAS (National Office of Urban Sanitation) and CRDA (Regional Office of Agriculture Development) are respectively in charge of the treatment and the reinjection whereas a GDA (Agricultural Development Group) is in charge of agricultural withdrawals from the aquifer.

Technical chain

The technical chain for wastewater reuse is described in Figure 30 below.

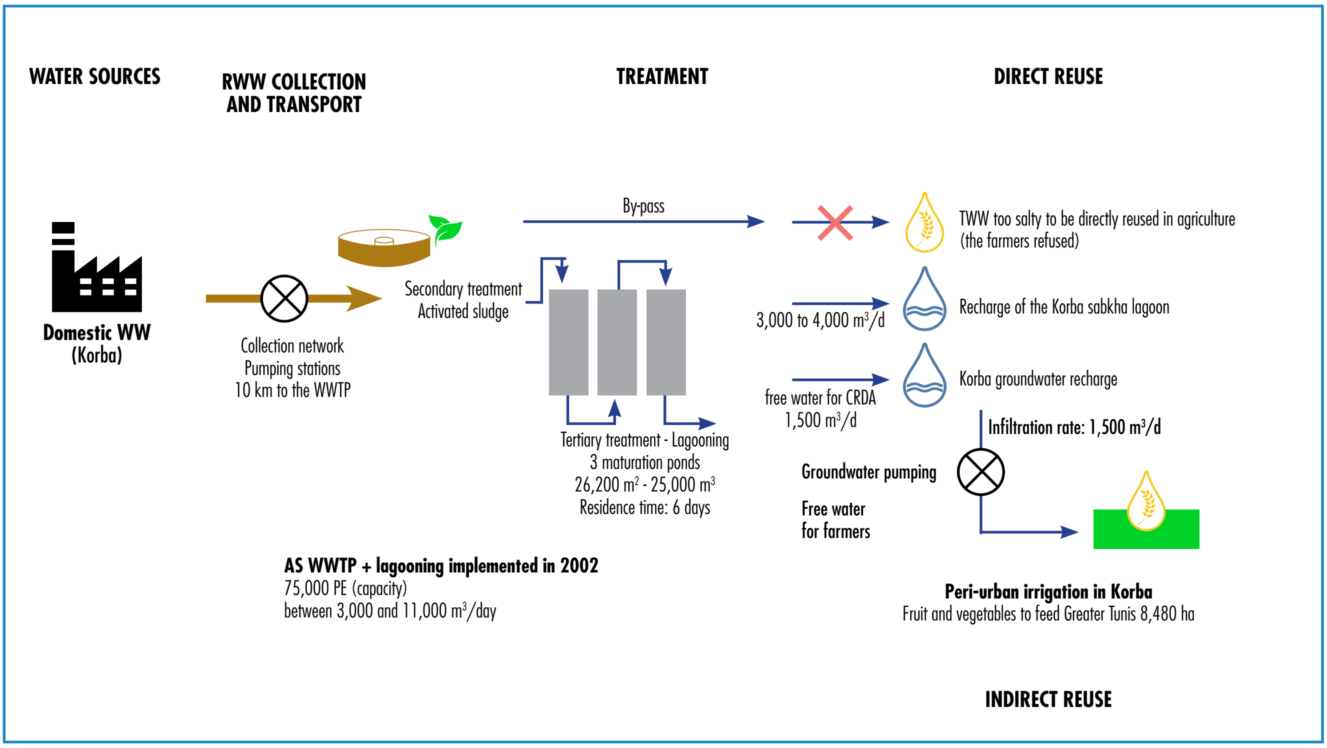
TWW is used to recharge a natural lagoon (sabkha) at the end of the tertiary treatment (lagooning after activated sludge).

A volume of 1500 m^3 of TWW is infiltrated each day into specific ponds so as to recharge the Korba aquifer. Reuse for agriculture is indirect: farmers take water from the aquifer to irrigate the outskirts of Korba.

Obstacles encountered and solutions implemented

The salinity of the TWW was a problem for farmers who refused to directly use this water after it was treated. After a residence time and dilution in groundwater, the salinity of the collected water is still high but the quality is compatible with the agricultural use. As a result, through the recharge of the aquifer it is also possible to restrict salt water intrusions.

FIGURE 30: The reuse chain in Korba, Tunisia - Ecofilae diagram



PROJECT 9
The reuse chain in the northern Gaza Strip in the Palestinian Territories - the NGEST project (not implemented in 2014)

Context and project objectives

The Beit Lahia wastewater treatment plant is in overload and the water is poorly treated before being discharged into a lake where infiltration is very low with high risks of groundwater contamination.

The NGEST project integrates the construction of a new wastewater treatment plant (Jabalya) and additional infiltration ponds, as well as groundwater pumping to supply irrigated areas.

The main objectives are to
- Support agriculture and relocate farmers on the areas of their land that are not being used for crops (by providing an additional source of irrigation);
- Solve the health problem caused by the discharge of poorly treated wastewater that ends up in a lake and the groundwater (used to produce drinking water).

Actors, operators and funders

The main project manager is the Palestinian Water Authority (PWA). Funding is provided by French, Swedish and Belgian development agencies, as well as the World Bank and the European Union.

Once completed, the project will be turned over to the Coastal Municipalities Water Utilities (CMWU). The CMWU, in collaboration with municipalities and through farmers' associations, will need to gradually improve the recovery rate to cover operating and maintenance costs and ensure efficient treated water delivery and use.

Technical chain

In the NGEST project, wastewater treated by the activated sludge treatment plant in Jabalya is indirectly reused by farmers after infiltration into the water table followed by pumping. It is planned that more than 2,300 ha will be irrigated by 2025.

The treatment chain for the Jabalya wastewater treatment plant is an activated sludge process, including digesters, air blowers and gas holders. The sludge is dehydrated and stored. A model of the treatment plant is shown in Figure 31 below.

The entire wastewater reuse chain is shown in Figure 32.

The TWWR project is being implemented in 3 steps:
- Step 1 in 2015: waste water produced starting in 2009 by the Beit Lahia plant is re-injected into the aquifer (estimated to be 20 mm3 in total). The water equivalent of the daily production of the Beit Lahia plant will be pumped to supply the irrigation network;
- Step 2 in 2020: 39,000 m^3 will be pumped per day to supply the irrigation network with treated wastewater from the Jabaliya plant;
- Step 3 in 2025: an additional 30,000 m^2 will be pumped when the capacity of the Jabaliya wastewater treatment plant will be increased.

Prior to the project, only 233 ha were irrigated (citrus, olive trees, fodder crops, fruit trees, but no vegetables). The official objective is to reach 2,300 ha in 2025. It is planned that the network will reach 103 km in length. With Step 3, it will be possible to transfer water to other areas. It is anticipated that the cost of water will be €0.23/m^3.

The wastewater treatment plant will be powered by methane generated during the treatment process and by solar panels.

Obstacles encountered and solutions implemented

Poor coordination between the various bodies of the PWA was constraining at the start of the project.

Wastewater from the Beit Lahia wastewater treatment plant was contaminated with groundwater. A monitoring program is now in place to ensure the safety of the infiltrated water (for both the Beit Lahia and Jabalya plants) and the water delivered, with daily groundwater modelling to examine the dispersion of the plume.

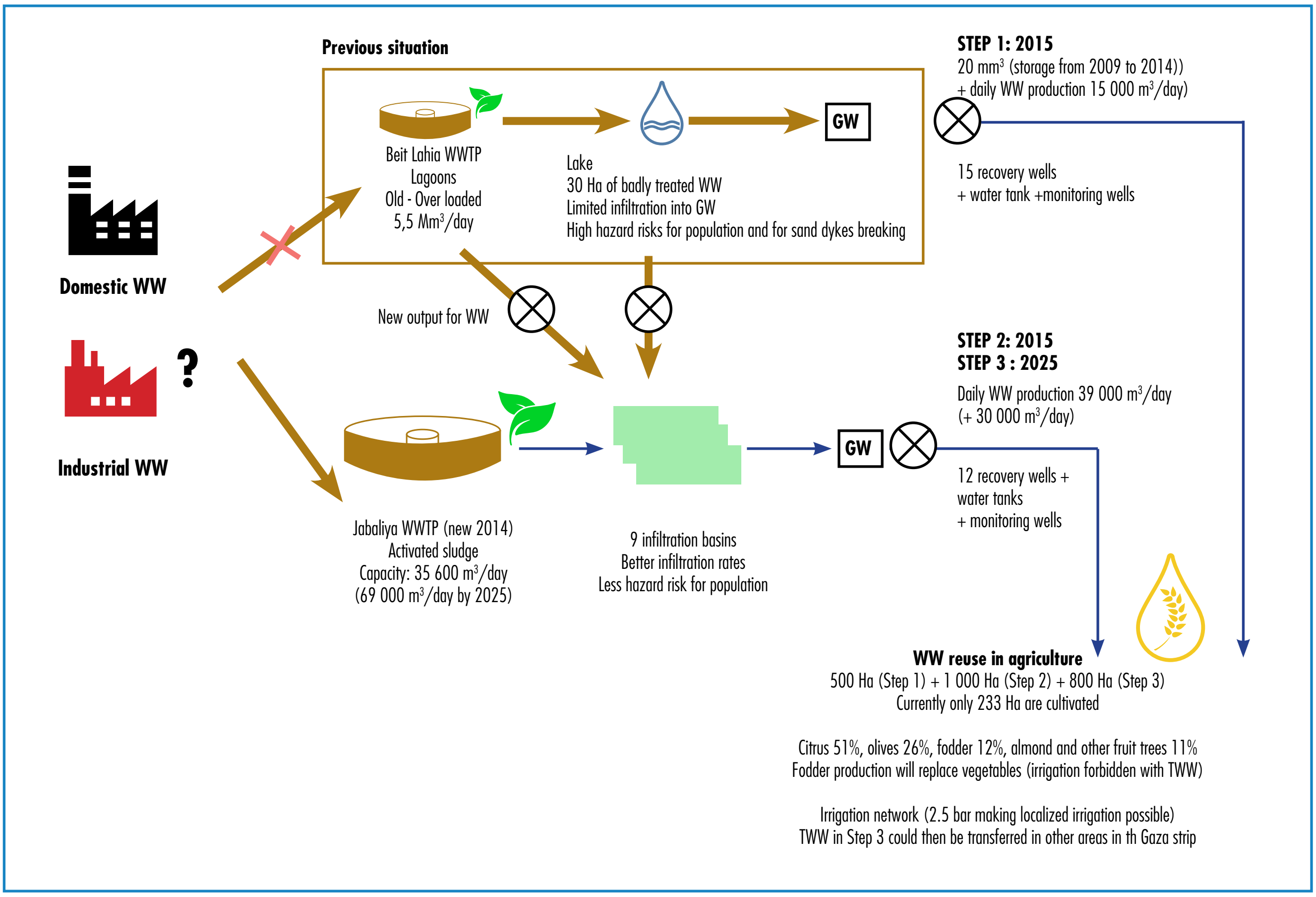
FIGURE 31: Model of the Jabaliya wastewater treatment plant – ICID 2015

The supply of energy to wastewater treatment plants and recurring power outages are a major challenge. Energy provided via emergency generators, solar panels and biogas plants must permanently keep the wastewater treatment plant operational and maintain irrigation of the area throughout the day.

The main challenges for the agricultural component are:

- The pumped groundwater contains high levels of chloride and nitrates. Farmers then switch to olive and citrus crops that support these high levels;
- The safety issue (proximity to the Green Line, the impossibility to cultivate crops further than 1 meter away from the wall, steady fatal shootings, etc.) is a threat to farmers;
- Agricultural competitiveness is limited due to the economic situation in the Gaza Strip;
- Competition for land is high within a context of population growth in the Gaza Strip;
- Financing mechanisms to meet the labour and investment needs of farmers are very limited;
- The institutional environment is weak and lacks technical support and advice provided to farmers;
- Farmer awareness and acceptability was very limited: this problem was partly solved through efficient user associations.

FIGURE 32: The reuse chain in the northern Gaza Strip in the Palestinian Territories – the NGEST project - Ecofilae diagram



PROJECT 10
The reuse chain in Harare (Zimbabwe)

Context and project objectives

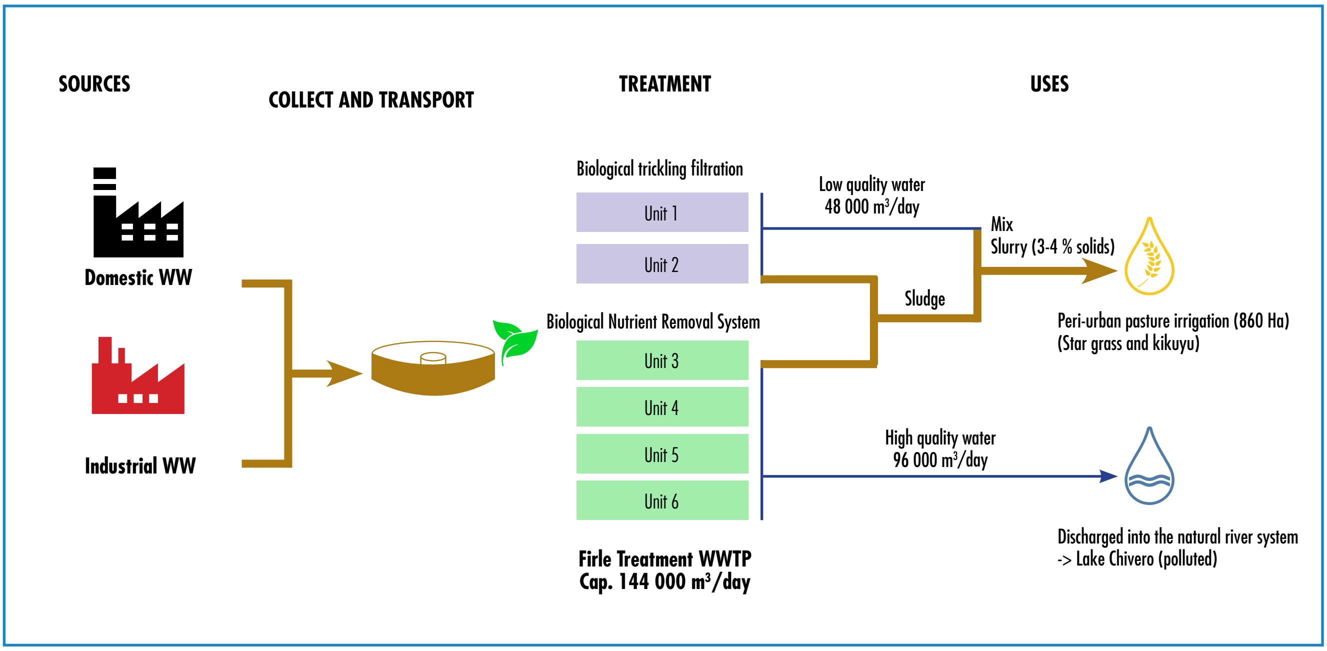
This project was developed and implemented within a context of water scarcity (need for more water resources).

Reuse chain

The reuse chain is described in Figure 33 below.

In the Firle wastewater treatment plant, two treatment chains were implemented and adapted to the various end uses. A biological nutrient removal system treats the water that is discharged into a natural river. A biotrickling filter system treats the water (sludge - suspended matter) which is then reused to irrigate pastures.

FIGURE 33: The reuse chain in Harare (Zimbabwe) - Ecofilae diagram



PROJECT 11
Experience in the city of Bogota (Colombia) - USAID 2012

Wastewater reuse is included in the integrated water management system for the city of Bogota. It is a strategic element even if there are abundant freshwater resources.

Several years ago, energy agencies developed a hydroelectric production system to use water from the Bogota River, downstream from the city of Bogota. The system meets approximately 20% of the city's energy needs and 7% of the country's needs. For this reason, the flow and quality of the Bogota River are considered a national priority by the Colombian government and are essential to the country's economic stability.

However, the city's wastewater is discharged (partially treated and untreated) into the Bogota River resulting in low quality water resources for peri-urban agricultural areas and energy production. The use of low quality water (from the Bogota River) in the agricultural sector has also led to high levels of soil salinity.

Two wastewater treatment plants have been planned in order to improve the water quality and to control discharge: the Salitre plant in the late 1990s, and the Canoas plant by 2016. Peri-urban farmers in the Ramada District will be able to directly reuse treated wastewater. They will stop taking water from the Bogota River (preserving the flows for hydroelectric production) and the peri-urban agricultural area could be expanded. The agronomic conditions (salinity) will also be improved.

PROJECT 12
Experiences in Libya

In Libya, at Hadba El Khadra (5 km from Tripoli), wastewater reuse began in 1971. Wastewater was treated in a "traditional" treatment plant, followed by a sand infiltration treatment and then chlorination (12 mg/l). Purified wastewater was then pumped and stored in reservoirs with a storage capacity of 3 days. A surface area of 3,000 ha of fodder crops, vegetables and windbreak plantations on sandy soils was irrigated. A volume of 110,000 m3/day was used and applied using pivot sprinklers (Angelakis 1999).

Reuse has also been implemented in Al Marj (to the north-east of Bengazi, 50,000 inhabitants) after water treatment with a biological treatment, sand filtration, chlorination and storage.

It was not possible to collect any project assessments for this study. They may only be operational in 2015.

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