LES SYNTHÈSES TECHNIQUES
DE L'OFFICE INTERNATIONAL DE L'EAU

Wastewater and excreta reuse

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February 2014

Office International de l'Eau

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TECHNICAL SYNTHESIS

Wastewater and excreta reuse

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ABSTRACT

This study is an overview of wastewater and excreta reuse and aims to analyze the socio-economic and institutional drivers and obstacles encountered by these projects in the developing countries. Water scarcity and demographic growth, implying an increase in food and water demand, are the main drivers of wastewater and excreta reuse projects. In developing countries, poor sanitation is often encountered and the result of unplanned reuse is responsible for serious sanitary and environmental problems. When implemented and controlled, the reuse can generate significant socio-economic and environmental benefits. Water and excreta reuse projects in developing countries are the occurring in response to a lack of sanitation and to agriculture and aquaculture needs.

RESUME

Cette étude recense des projets de réutilisation d'eaux usées et d'excrétas dans les pays en développement et a pour objectif d'analyser les moteurs et les freins socio-économiques et institutionnels rencontrés dans leur élaboration. Le manque d'eau, la croissance démographique ont pour conséquence une augmentation de la demande en nourriture et en eau. Ce sont les moteurs principaux des projets de réutilisation des eaux usées et des excrétas. Dans les pays en développement, l'assainissement fréquemment déficient est à l'origine de réutilisations spontanées d'eaux usées non sans conséquences sanitaires et environnementales. La réutilisation d'eaux usées et d'excrétas lorsqu'elle est encadrée et contrôlée est génératrice de bénéfices socio-économiques et environnementaux. Les projets de réutilisation d'eaux usées et d'excrétas permettent de pallier à la fois à un manque d'assainissement et de répondre aux besoins de l'agriculture et de la pisciculture.

Introduction

Wastewater and excreta reuse (WR) is a practice occurring worldwide for centuries. This practice consists of the use of wastewater and excreta (WE) treated. The treated wastewater and excreta reuse (TWWR) planned and controlled offers socio-economic, sanitary and environmental advantages. In developing countries (DC), the high demographic growth implies an increase of the food and the water demand. The WE recovery in agriculture and aquaculture is an interesting solution to reply to these new challenges. In arid and semi-arid regions where level of water scarcity is high, WE should be considered as the water resource. In DC, the main natures of recovery are agricultural and aqua-cultural but not exclusively.

TWWR projects take into account the issue of sanitation. In DC, the high urban demographic growth implies an increase of the wastewater volumes produced. Often, the existing sanitation network cannot treat these. Some unplanned reuses are occurring in response to this lack of sanitation comporting high sanitary and environmental risks.

In this context, the TWWR projects allow to face at the same time a lack of sanitation and to reply to some needs of recovery. Most of the time in developed countries, all the types of wastewater are collected in the same sewage system. It is not the case in DC and this separation of the different domestic wastewaters offers a panel of alternative and low cost sanitation processes.

This synthesis aims to list the different natures of recovery in DC and to analyze their socio-economic, environmental and sanitary issues and bottlenecks. In the first part, the different WE and the treatment processes preceding their reuse are presented.

DOMESTIC WASTEWATER AND EXCRETA

DIVERSITY AND ORIGIN OF THE EFFLUENTS OF THE DOMESTIC SANITATION

There are six types of domestic effluents:

- Blackwater: composed of urine, excreta, flushed water. These waters contain nitrogenous and phosphorous organic matter, faecal pathogens and also micro-pollutants.
- Greywater: wastewater from kitchens, bathing and washing. These waters contain detergents, fats, solvents, organic debris and micro-pollutants. Their pollutant load is less than those of the blackwaters, containing 20 times less of organic matter.
- Faecal sludge: from septic tanks and emptying latrines, composed of greywater and blackwater.
- Excreta: mix of faeces and urine.
- Urines
- Faeces

Depending on the way they are collected, domestic wastewaters could be composed of one or more types of these effluents. Conventional networks of sewage used to mix greywaters and blackwaters. Only isolated houses are not connected to the sewage network and possess their own onsite-sanitation system. This individual sanitation system sometimes separates greywaters and blackwaters. Most of the time, in DC greywaters and blackwaters are separated. The Table 1 below presents the effluent types in function of the collecting sanitation system.

Sanitation sector	Collecting system	Effluent types
Collective or semi-collective	Sewage	- Greywaters + blackwaters
Semi-collective	Mini -sewage	- Greywaters + blackwaters OR Greywaters
Non-collective	latrines or septic tanks	- Faecal sludge composed of excreta
Non-collective	Dry toilets, urine-diversion latrines	- Faeces - Urine

Table 1. The 6 domestic effluents

THE DIFFERENT SANITATION TREATMENTS AND THEIR BY-PRODUCTS

Treatment of the greywaters mixed with blackwaters

In the collective sanitation sector, greywaters mixed with blackwaters are conduced to a waste water treatment plant (WWTP) via a collecting network or sewage. In this WWTP, they will be treated by the following typical treatment chain consisting of the succession of pre-treatment, primary and secondary treatments before going back into the natural environment. If the effluents treated are rejected in a sensitive area or will be reused, a tertiary treatment and disinfection is required. The choice of these adding treatments should be considered in link with the quality criterions needed or the nature of the recovery planned. The minimal quality for the reuse must comply with the guidelines of the World Health Organisation if there is no legislation. Some countries have their own legislation.

The Figure 1 presents three possible treatment chains for a mixture of greywaters and blackwaters in consideration with a nature of reuse. The by-products of the sanitation processes are also mentioned and require treatment before their re-introduction to the natural environment or their reuse.

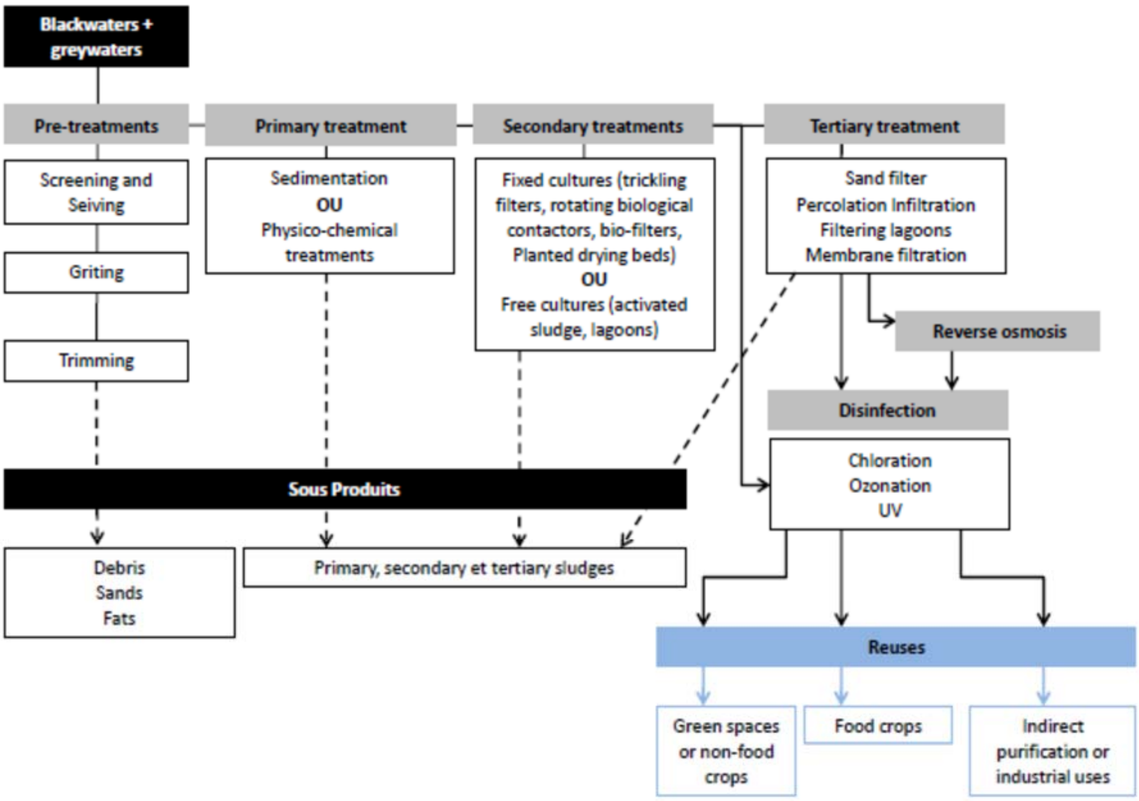

Figure 1. Treatment chains of wastewater and their by-products for different natures of reuse

At their arrival at the WWTP, the effluents are pre-treated in order to eliminate the big waste objects, sand and fats. Then, they go through the primary treatment in order to eliminate the suspended mineral and organic matter. Note that the primary sedimentation is a low cost process compared to the physic-chemical treatments. The primary effluents enter then in the secondary treatment chain aiming to decrease the dissolved pollution. At the end of the secondary treatment they could be directly disinfected if their suspended matter content is low (UV disinfection requires a rate of suspended matter lower than 5 mg/L). Otherwise they are conduced to a tertiary treatment chain in order to decrease their rate in phosphorous and nitrogenous matters. This treatment could be followed by a reverse-osmosis and disinfection, If the reuse requires a high water quality (e.g industrial), or only disinfection if the reuse is for example agricultural.

The more effluents are treated and more the quantity of by-products and the sanitation more costly. The treatment of the biosolids is presented in the next chapter.

Treatment of the blackwaters, faecal sludge, biosolids and faeces

For non collective urine-diversion sanitation systems, faeces are collected in tanks. Their sanitation is realized on site or in WWTP equipped with an adapted sanitation system. The content is particularly interesting for agricultural recovery, and has been used for centuries as fertilizers. The storage is the easiest on-site treatment of the faeces but this process is slow. Several months to several years are needed to deactivate the pathogens and to obtain an inoffensive fertiliser. Some pathogens are able to develop anew if water infiltrates the tank or if the matter is mixed into humid soil (Austin et Van Vuuren, 2001). This practice is not totally secure but has a real interest over warm and dry regions.

Figure 2 presents several processes for the treatment of blackwaters, faecal sludge, biosolids and faeces. These three effluents will be named «bio-solids » in the following part. The liquid biosolids will be thickened and dehydrated in order to increase their dry content and lead them to solid form. Many technical solutions exist to realize this process, but the most interesting for agricultural reuse is the addition of lime. In fact, it allows at the same time to eliminate the pathogens and to increase the nutrients contents of the biosolids. The products obtained could be treated by a complementary treatment.

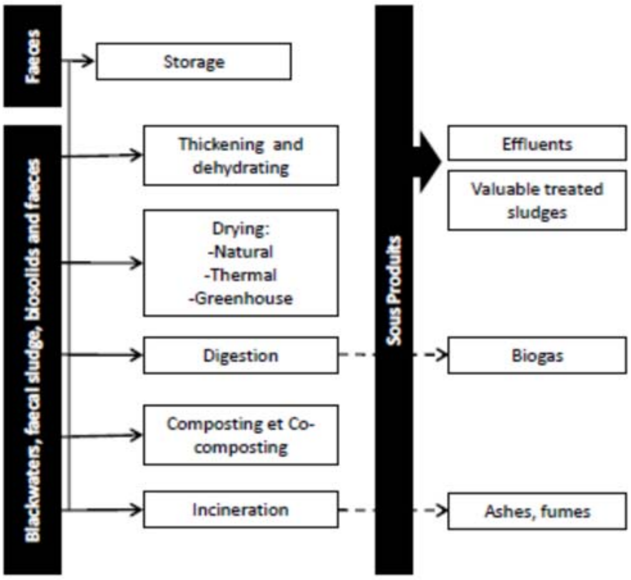

Figure 2. Treatments of the blackwaters, faecal sludge, biosolids and faeces and the by-products associated

Drying processes dehydrate biosolids more efficiently than the thickening and dehydration. The biosoldids are almost free of pathogens and their content in nitrogen and phosphorous is preserved. Thermic and green-house drying processes are costly. The natural drying requires large areas and comports olfactory nuisance.

The effluent digestion by biological degradation of their organic matter is another solution allowing the decrease of volume by 30 to 40%. The biosolids obtained are partially free of pathogens and need to be treated. The biogas produced during the process could be recovered. Note that the cost of this solution is particularly high.

Composting is an alternative low-cost solution to treating the biosolids. This process consists of an aerobic decomposition of the organic matter by micro-organisms in a controlled environment. The pH variation and the high biological activity occurring in this controlled environment allow the pathogen elimination. Usually a co-product (e.g green waste) is added in order to increase the efficiency. The compost obtained is free of pathogens and has a high agronomical value.

The most secure process is probably incineration. The fertilizer produced is composed of ash and totally free of pathogens. Nevertheless, the process induces the loss of nitrogen and is particularly expensive.

All the biosolid treatment processes, except the incineration, produces liquid effluents with a high pollutant load and have to be treated by one of the treatment chains described in the Figure 1.

Treatment of greywaters

Greywaters represent the biggest volumes of the wastewaters produced. Their pollution rate is lower than those of faeces, blackwaters, excreta and faecal sludge. They are collected by a semi-collective network. In developed countries, such as in Sweden or Germany, the greywaters of some eco-quarter are conduced to a small WWTP where they go through a primary treatment (e.g. sedimentation) and then to secondary treatment (e.g. reed bed). This chain is sufficient to eliminate the pollution. The effluents can be rejected safely to the natural environment, or be reused to toilet flushing or restricted gardening. In DC, greywaters are often discharged in trenches and decant under the sun. The sanitary risk associated to their direct reuse is low. Nevertheless, the fat contained in these waters can block up the networks and regular cleaning is needed. The environmental impact of micro-pollutants coming from the detergents and cosmetics contained in these waters is today not known.

Treatment of urine

The deviation-urine sanitation systems collect urine in tanks. This type of system is particularly interesting because urine needs little treatment. Schönning and Höglund (Schönning et al., 2004; Höglund, 2001), have shown that the high pH and temperature are the factors that inactivate the pathogen micro-organisms contained in the urines. One month storage at ambient temperature (20°C) or a few weeks storage in hotter countries is sufficient to purify them. Their nitrogenous, phosphorous and potassium content make them interesting for agriculture. An alternative process is drying in trenches where it has been experimented with in Mali and Sweden (Schönning et al., 2004). During this process the nitrogen is lost but the phosphorous and potassium preserved.

The issue of sanitation product recovery

Global sanitation situation

The treatment of human waste or the lack of treatment raises significant sanitary problems especially in DC. Basic sanitation is a necessity for health and dignity. Nevertheless, today almost 41% of the world population (2.6 billion of people) live without proper access to a sanitation system.

This portion of the world population is mainly located in DC of Sub-Saharan Africa, parts of Asia, South-America and Central-America. According to the WHO and the Unicef (United Nations International Children's Emergency Fund), this portion should be reduced to 2.4 billion of people through the seventieth millennium development goal (MGD). It aims to halve the portion of the population without access to a basic sanitation between the years 1990 and 2015. Today, it has been estimated that this goal will be missed by 8% or half-billion people. The sum for providing basic sanitation for these people is less than 1% of the world military spending in 2005, one-third of the estimated global spending on bottled water, or about as much as Europeans spend on ice cream each year (LeBlanc et al., 2009). The efforts made in the context of the MDG focus on household access to sanitation but do not take into account the issue of WE treatment. In DC, the progresses are unsatisfying and often hide a lack of WE treatment.

In Eastern Europe, Turkey, Russia, Mexico, parts of South America and other regions the water treatment is advanced but the sanitation by-product management started only to be considered. In Europe, North America, Australia, New Zeeland, the sanitation is efficient and these countries focus now on the improvement of the sanitation by-products management. They also have the necessary technical skills and decisional means to consider and implement solutions.

In DC, according to the WRI (World Research Institute), the population is growing at 3.5% per year while in developed countries this increase is 1%. 95% of this growth will be absorbed by the DC cities that have no or poor sanitation access. According to UN-Habitat their population should reach 2 billion from 2030. So water needs will be growing and water resources are limited. A growing pressure on the water resource will be experienced also in developed countries due to the increasing longevity of their population and the chemical pollutions of their resources. The WE production, unavoidable consequence of the potable water use, will increase.

Adding to the demographic pressure, the global climate change will impact the situation by an increase of the natural hazards and drought episodes.

The combination of these factors will make the access to potable water problematic and a potential source of conflict. The WHO estimates that in 50 years 40% of the world population will live in regions facing water stress. In this context, sanitation and by-product management are global issues with growing concerns, requiring the awareness of all decision-makers and the public

Blackwater, faecal sludge, excreta, urine and faeces are made of molecules from the food and the physiological degradation processes. These molecules contain nutrients: nitrogen (N), phosphorous (P), potassium (K) and micro-nutrients: copper, iron, nickel and zinc involved in plant growth. Their value has been recognized for a long time in the agricultural world. Greywater contain fewer nutrients but constitute a water resource available throughout the year, which make them particularly interesting in arid and semi-arid areas. The Table 2 gives the average nutrients composition of domestic wastewater and excreta.

Componant	Greywaters	Urine	Faeces	Excreta (Urine + Faeces)
Mass (kg/pers/yr)	40000	550	40	590
Dry mass (kg/pers/yr)	29.2	21.9	18	40
N (g/pers/yr)	460	4015	548	4563
P (g/pers/yr)	110	365	183	548
K (g/pers/yr)	1000	1100	400	1500

Table 2.Composition average nutrient composition of domestic wastewater and excreta (Vinneras, 2002)

Beside valuable components greywater contain fats, solvent, detergent and micro-pollutants which nuisances have been described in the preceding chapter. Blackwater, faecal sludge, excreta, urine and faeces contain pathogens. Greywater also contain pathogens but in a fewer amount. Health risks associated to the WR are widely described in the WHO guidelines and will not be detailed in this synthesis.

Characterizing with accuracy domestic wastewater and excreta is difficult because the diets and the amount of domestic water used vary within the world region considered. Jönsson and al. (2005) overcame these difficulties and made a model of the excreta composition for an accurate diet. This model could be relevant to prepare a WR project. The greywater composition is an actual research theme, particularly concerning micro-pollutant characterization. Rich information exists in the scientific literature.

WE by their water and nutrients contents represent a precious resource. Their use in aquaculture and agriculture, recover the nutrients and reduce the use of fertilizers. The non-renewable phosphorus, essential to produce fertilizer, is expected to run out by the end of this century. The excreta use only would allow 22% of the global phosphorous demand. In DC consuming 63% of the global amount of fertilizers, the WR is particularly interesting (World Health Organization, 2006).

WASTEWATER AND EXCRETA REUSE PRACTICES IN DEVELOPING COUNTRIES

WHERE IS RECOVERY PRACTICED?

The WE recovery is an ancient and worldwide practice. In China and in Europe, before the implementation of WWTP, their fertilizer content was recognised and the WE were often spread on farmlands. Oldest WR are attributed to Asian countries, where for thousands of years, the WE were used in aquaculture. In developed countries, there has been a decline of these practices along with sanitation progress. It is only recently that the reuse of EU was given to date by enrolling in an environmental approach. In developing countries, it is necessary to differentiate between planned reuse practices that try to address matters such as economic or physical water scarcity, and spontaneous and unplanned reuse practices resulting from missing or defective sanitation.

In industrialized countries, 70% of fresh water is used for agricultural irrigation, 8% for domestic uses and 20% for industrial uses (Drechsel, 2010). It's therefore not surprising that the WR in DC is mainly agricultural and piscicultural. In these countries the WR practices are difficult to quantify either because the volume of water used are simply not valued, or because the information is hidden as a consequence of illegal practices or for reasons of acceptability by population. Despite this lack of information, the UNHSP (LeBlanc et al., 2009) estimates that 4 to 6 hectares are irrigated with WE (treated or not) i.e. 1.5% of the world irrigated lands, according to the FAO (Food and Agriculture Organization). The Figure 3 is the result of a study which has quantified the TWWR for agricultural irrigation.

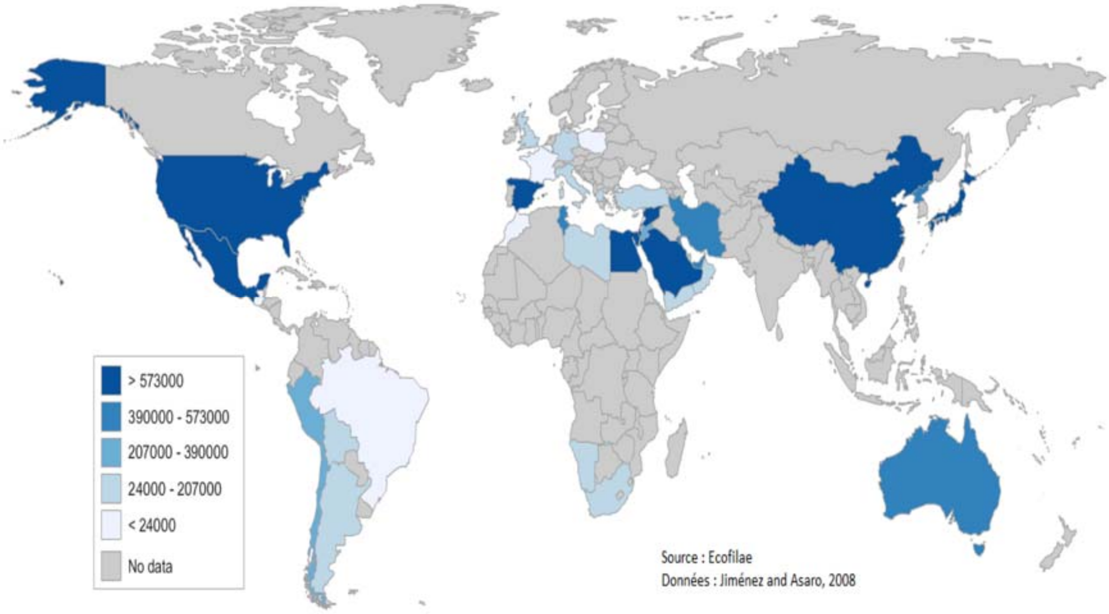

Figure 3. Treated wastewater reuse for agricultural irrigation (in m^3/day). (Condom, 2012)

Case Study

By compilation of bibliographic information, 44 cases of WWR have been identified in developing and emerging countries of the Maghreb, the Middle East, Sub-Saharan Africa, South America and Asia (See Annex « Listing of referenced cases »). The natures of the different recoveries prevailing in these countries are presented in Table 3 below.

Recovery nature	Number of cases identified
Agricultural	28
- Cereal crops - Vegetable crops - Pastures - Industrial plantations	
Piscicultural	6
Industrial	8
- Phosphates leaching - Refinery - Fertilizer plant	
Environmental	5
- Forest irrigation - Aquifer Recharge - Fight saline intrusion - Support low water - Fight eutrophication	
Urban	5
- Watering of green spaces and gardens - Urban cleaning	

Table 3. Natures of recoveries of wastewater and excreta reuse

The same project can be associated with several natures of reuses, which explains why the total number of cases by type of recovery is greater than the number of cases studied. This census (non-exhaustive) of projects agrees the expected trend with the predominance of reuse for agricultural purposes.

Accurate nature of the recoveries

Among the different cases identified five have been for a more detailed analysis. The choice of these cases is based on their representativeness among nature valuations identified in Table 3. Quantitative information about these projects are not always clear or precise due to a lack of bibliographic information.

Case n°1: Korba, Tunisia

This project started in 2008, was based on the achievements of completed project in Nabeul (Tunisia). It aims to reuse the WE (greywaters + blackwaters) of the Korba city to refill an aquifer close to the WWTP via three infiltration basins (Agence Française de Développement et BRL Ingénierie, 2011). In Tunisia 80% of the fresh water is used for agricultural irrigation. This region is under water stress and consequently the aquifer resources are overexploited. The 100 000 inhabitants of Korba city generated each day 5000 m^3 of WE. The effluent was conduced and treated by a primary and a secondary treatment in the WWTP. Then, the treated water was used to fill the three infiltration basins of a surface of 4500 m^2 (3x1500 m^2) and an infiltration rate of 1500 m^3/day. Percolation through the geological layers compensates for tertiary treatment. The rate of groundwater recharge is estimated at 0,5.106 m3/year (Cherif et al., 2013). The percolation retains the pollutants of the effluent but some pathogens still remain in the effluent refilling the aquifer. Due to the water quality of the aquifer the standards recently developed by the Tunisian authorities allow its use only for irrigation. The aquifer recharge provides additional resources for irrigation of 8480 ha of agricultural land in the region. The aquifer recharge also fights the saline intrusion. This experimental project has a dual agricultural and environmental dimension.

Case n°2: Dakar, Senegal

This TWWR project of the Senegalese NGO ENDA (Environmental Development Action in the Third World) and LATEU (Laboratory for Analysis and Wastewater Treatment Dakar) project aims to provide safe TWW for the peri-urban agriculture in the Niaye of Dakar by implementing pilot stations in quarters of the Dakar city.

The region of Dakar and the Niaye of Dakar are a part of the Niaye region which constitutes the north coastal region of Senegal. It is composed of dunes and depressions favourable to the vegetable peri-urban agriculture. This area, 180 km long and approximately 20 to 30 km wide, produces 80% of the vegetable consumed in the country. The peri-urban agriculture practiced in Niaye of Dakar is a practice expanding in main African cities. This activity is the only source of income for half of the farmers who are in majority poor migrants from rural areas. Because of the frequent use of untreated WE the peri-urban agriculture involves health problems and, salination and alkalinization of soils. For example, in the Dakar region only the Niaye of Pikine, representing an area of 16 ha, 32% of the irrigation of vegetable crops is done with wastewater. This Niaye counts 5,000 farms and 1,500 producers all belonging to the informal economy. They are small producers, farm employees, wholesale buyers, retail merchants, transporters, processors, farmers and input sellers (Andre et al., 2010). Only 850 gardeners in this area use the EU to irrigate their land. They prefer to use this resource, found that their crops matured faster.

The first step of the TWWR project initiated in 1994 with the installation ENDARup pilot station in the district of Castor. This station consists of a sedimentation basin and six lagoons with water lettuce and is able to treat the 75 m^3 greywaters produced per day by the district. For a residence time of 38 days, the effluents reach the WHO standards for irrigation (Andre et al., 2010). The water can then be reused safely to irrigate crops. In 2003, the second step of the project was the pilot station installation in the neighborhood of Yoff Tengor. The greywater treatment is realized by a sand filter and the excreta are collected in septic tanks. In 2012, began the study of the third step concerning the upgrading of excreta treatment. The treated wastewater is used for irrigation of vegetable crops (unknown volumes). The excreta are already collected separately in septic tanks and composted before their reuse as fertilizers.

Case n°3: Cuttack, Kokalta (Calcutta), India

Calcutta has the largest aquaculture complex in the world with 3800 ha supplied by WE (blackwater + greywater) (World Health Organization, 2006). In the eastern region of Kokalta, the city of Cuttack (10 million inhabitants) uses a traditional technique to purify its WE and is an example for multiple reuse aquaculture and agriculture (Raychaudhuri et al., 2008). Everyday 10,106 m3 of WE are conducted via channels to an experimental station established in 1994 and located about ten kilometers from the city. The sanitation processes are based on ancestral techniques. The primary treatment occurs in ponds containing duckweed and the secondary in ponds containing carp and shrimp. The living organisms in these ponds allow a reduction of COD and almost complete reduction (96 % to 99 %) of faecal coliforms. After five days, the water quality is improved and can be used for irrigation of vegetable crops. This system can handle a third of EU city and supports 4,000 families (Raychaudhuri et al., 2008).

Case n°4: Chennai, India

The municipality of Chennai provides since 1991 a part of its treated WE by a secondary treatment at two factories. Madras Refinery receives 12,106 l/day and the Fertilizer Plant Madras 16.106 l/day. The latter has on-site sanitation facilities to complete the treatment of the secondary effluents by a tertiary treatment and a reverse osmosis. The treated effluents are reused in industrial processes (Vinod et al., 2011). The complementary treatments operated in these plants achieve the quality objectives required by the industrial processes. These facilities are financially viable and their cost amortized (Vinod et al., 2011).

Cas n°5 : Mezquitalvalley, Mexico

The "Mezquitalvalley" is the largest area in the world (90 000 ha) irrigated with partially treated WE from Mexico City. Agricultural activity practiced in this area is a source of income for 60,000 families. This practice started in 1896 to overcome the lack of sanitation. Today, sanitation has been developed and 60 % of the WE from Mexico City, i.e. approximately 150,000 m3/day, should be treated (Jiménez and Asano, 2008). The Mezquital Valley is located above an aquifer and the irrigation in this area induces its unplanned refill not without damage. Mexico City faces water shortages and a project to use this resource in order to produce drinking water is being studied.

Among the cases presented, only Tunisia has its own legislation. Mexico City is currently writing a legislation and the other countries should in theory agree to the WHO guidelines.

ANALYSIS OF THE PRACTICES IN DEVELOPING COUNTRIES

THE DETERMINANTS IN THE REUSE PROJECTS

The cross-case analysis of WWR projects realized in the previous section identifies as major reuse the agricultural irrigation. The second major reuse is the use of EU aquaculture. This is consistent with the distribution of current proportions of use of fresh water (see p. 9). The motivation of the WWR projects is relatively independent from political decisions. Most of them are still experimental approaches and pilot actions. Today few or no countries have systematized the WWR by including and integrating it into national policies. WWR projects are motivated by a combination of factors such as water scarcity, urbanization and growing demand for food. This is more the socio-economic context and water stress of the countries, which determines the nature of the recovery (Plan bleu pour la Méditerranée et al., 2012). The most representative example met in sub-Saharan Africa and parts of Asia is peri-urban agriculture. This practice is expanding in response to the strong growth of the urban population, food prices rising and poor sanitation. The farmers are often poor people (usually rural recently migrated to the cities) and this activity is for most of them their only source of income.

THE ACCEPTABILITY OF THE RECOVERY PRODUCTS

Among the case studied on the use of EU for irrigation, Senegal, Vietnam and Mexico, farmers prefer to use the WE because of their nutrient content. Nevertheless, in water stressed areas, a certain mistrust of the establishment of a WWR project is observed due to the amount of volumes allocated to the different resource uses. The implementation of the project in Korba, sharing the resource between environmental and agricultural purposes was the subject of protests by farmers. This shows the need to integrate the WE to water resource management plans.

In countries where planned or unplanned WWR is practiced for a long time the users are more conciliatory towards TWWR projects providing them a more secure resource. This is not the case for all regions of the world or all types of recovery. The population then needs to be aware and informed in order for a TWWR project to be accepted and not generate irrational fears.

The factor perhaps the most determinant for the acceptability by the users of treated WE resource is its price. It has to be adequate to socio-economic context of the users. The implementation of a TWWR project modifies the behavior of users who must adapt to a new type of use of water resources and payment. If the issues of the project are not well received and understood by the population, it has every chance of being rejected. There are several examples of pilots stations abandoned. In the case of agricultural recovery, the farmers need to be trained in order to adopt good and safe practices. In developing countries, where the practice is not historically rooted consumers ignore it most of the time and they consume products from the reuse of WE which is not free of risk.

ECONOMIC ISSUES

Economic issues of the TWWR projects should be considered in the long term and the infrastructure required involving a significant financial investment. Policy makers often underestimate the economic viability of TWWR projects. The cost-benefit analysis (CBA) is a tool assessing the socio-economic impact of a TWWR project in the long term. This tool could help the stakeholders in their decision-making. ACB in France have demonstrated that golf courses irrigated with treated wastewater is more profitable in the long term than the use of conventional water. In DC, to our knowledge the TWWR projects have not been analyzed by this tool. However, in those countries where sanitation could be deficient, the controlled TWWR is an interesting alternative to expensive conventional sanitation and therefore economically viable over the long term. In DC, it is necessary that the pilot projects are rigorously analyzed economically about the overall profitability of investment, operating costs and terms of recovery of these costs.

Another major bottleneck observed in the cases studied, mainly located in cities undergoing rapid urbanization is availability of land. It is difficult for project leaders to stand up to local institutions about the acquisition of land required by TWWR.

SANITARY ISSUES

When planned and controlled, the TWWR presents no health hazards. However, when its use for irrigation is located close to an aquifer, it can contaminate drinking water resources because there will not be the quality required for such use. This is the case of the Mezquital Valley where WE is used to irrigate crops and has led to an unplanned refill of an aquifer thus compromising its direct use in drinking water. In DC where there is spontaneous and unplanned WWR it presents real health hazards. Some studies show that TWWR can be a vector of pandemics. In a context of water scarcity, managers of TWWR may be obliged under farmer-pressure to deliver non-finalized products with potential health and environmental risks. The health risks are real and could be serious. The TWWR therefore raises the issue of health compliance in developing countries, which comes in at least three questions: How to monitor? By who? How to finance?

ENVIRONMENTAL ISSUES

The TWWR can damage and regenerate the environment. When its environmental impact is misjudged, its use can lead to salination and destructuring of soils in the case of agricultural reuse or lead to eutrophication of natural environments. As for the health aspects, this aspect seems particularly neglected, and the same issues arise in measurement and controls.

SOCIAL ISSUES

TWWR projects generate jobs as shown by the Kokalta example. Jobs are created within WWTP but also their surroundings when the project requires a conveyor for the transport of human waste from septic tanks. Irrigation of surfaces by TWW induces an increase of the agricultural productivity and creates jobs related to the production and the product commercialization. However, these jobs are dependent on the economic strength and the viability of the TWWR project (see Economic issues).

CONCLUSION AND PERSPECTIVE

In DC, TWWR projects there are economic, social and environmental assets. They are particularly attractive for agriculture, which is the most spontaneous consumer.

However, these projects lack of visibility concerning their economic viability and as well as the financial, environmental and social benefits they can generate. Theses constraints prevent their massive development. Another bottleneck is the inherent risk associated with the recovery of an initially pathogenic material. The issue of health and environmental risk is raised and few DC today are able to ensure a safe use. Nevertheless, a number of indicators suggest that the TWWR will have a key role in the future. Different continents are experiencing rapid urbanization and growth in food demand associated with pressure on their water resources. The TWWR offers a range of solutions to face these challenges, such as the development of peri-urban agriculture, aquifer recharge, the fight against saline intrusion in coastal cities and the development of sustainable city concepts and eco-districts.

To better understand the TWWR and promote its development it would be required:

• To broaden the knowledge of the costs of TWWR especially those related to investment, operation, maintenance and service for the main existing sectors, in order to help economists and local decision-makers in their choices with more understanding.

• To clarify the socio-economic, cultural and environmental configurations for which the TWWR is a relevant option and is able to offer products suited to the local demand, and economically competitive.

• To improve the knowledge tools by creating practical and methodological guides for policy makers and local actors to implement TWWR projects.

• To consider and reference the case of transfer of a spontaneous and risky WWR, to a TWWR, controlled and certified as free of health and environmental risks.

• To understand better the perception of the TWWR by the policymakers who are the only ones able to stimulate the sector significantly.

• To develop a realistic health and environmental monitoring.

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ANNEX « LISTING OF REFERENCED CASES »

N°	Location	Country	Effluents	Nature of the recovery	Reference
	MAGREB AND MIDDLE EAST				
1	Korba	Tunisia	Treated wastewater	Aquifer recharge Fight saline intrusion Environmental protection	(Agence Française de Développement et BRL Ingénierie, 2011) (Cherif et al., 2013)
2	Khouribga	Morocco	Treated wastewater	Industrial : phosphates leaching	(Plan bleu pour la Méditerranée et al., 2012) (Condom, 2012)
3	Amman	Jordan	Treated wastewater	Irrigation of cerealcops Support low water	(Agence Française de Développement et BRL Ingénierie, 2011)
4	Sekem	Egypt	Treated wastewater	Irrigation of forests	(Vinod et al., 2011)
	SUB-SAHARIAN AFRICA				
5	Ouagadougou	Burkina Faso	Treated wastewater	Irrigation : Peri-urban agriculture	(Agence Française de Développement et BRL Ingénierie, 2011)
6	KeurSaïb N'Doye - Thiès Nord	Senegal	Treated wastewater	Irrigation : Peri-urban agriculture Breeding Aquaculture Watering of green spaces	(Andre et al., 2010)
7	*Niayes de Pikine et Patte d'Oie -* Dakar	Senegal	Wastewaters treated/raw Diluted wastewater	Irrigation : Peri-urban agriculture Fight soil salination	(Gaye et Niang, 2010)
8	Niamey	Niger	Treated wastewater	Aquaculture	(Louali, 2003)
9	Yaoundé	Cameroon		Aquaculture	(Tanawa E., 2003)
10	Kumasi	Ghana	Faecal sludge Treated wastewater	Agriculture Irrigation : - Vegetables crops - Horticulture - Green spaces	(Scott et al., 2004)
11	Nairobi	Kenya		Irrigation	(Scott et al., 2004)
12	Harare	Zimbabwe	Treated wastewater	Irrigation of pastures	(Jiménez et Asano, 2008)
13	Mutare	Zimbabwe	Sludges	Irrigation of caoutchouc	(Jiménez et Asano, 2008)
14	Bulawayo	Zimbabwe	Treated wastewater	Irrigation of caoutchouc	(Makoni, 2012)
15	AddisAbeba	Ethiopia	Treated wastewater	Irrigation	(Teklu, 2012)
16	Gaborone	Bostwana		Irrigation : agriculture, golf, gardens	(Masundire et al., 2012)
	ASIA				
17	Singapour	Singapore	Treated wastewater	Industrial	(Vinod et al., 2011)
18	Hanoï	Vietnam	Treated wastewater	Peri-urban agriculture Aquaculture	(Khai et al., 2007) (Raschid-Sally et al., 2001)
19	Tianjin	China	Treated wastewater	Industrial and municipal	(Jiménez et Asano, 2008)
20	Beijing	China	Treated wastewater	Industrial	Jiménez et Asano, 2008)
21	Bangalore	India	Treated wastewater	Industrial	(Vinod et al., 2011)
22	Chembur	India	Treated wastewater	Industrial	(Vinod et al., 2011)
23	Chennai	India	Treated wastewater	Industrial (Refinery and fertilizer plant)	(Vinod et al., 2011)
24	Vadodara	India	Treated wastewater (highly polluted)	Industrial	(Vinod et al., 2011)

25	Ganganagar	India	Treated wastewater	Irrigation of vegetable crops Toilets flushing	(Vinod et al., 2011)
26	Madras	India	Treated wastewater	Domestic: - Gardening - Toilets flushing	(Vinod et al., 2011)
27	Kokalta	India	Treated wastewater	Aquaculture Agriculture	(Bunting, 2007), (Costa-Pierce, 2005), (Raychaudhuri et al., 2008)
28	Haroonabad	Pakistan	Treated wastewater	Agriculture	(Hoek, 2002)
	SOUTH AMERICA				
29	Mezquital valley, Mexico	Mexico	Treated wastewater	Irrigation (world largest area irrigated with wastewaters)	Jiménez et Asano, 2008)
30	Juarez	Mexico	Treated and untreated wastewater	Irrigation A terme : Industriall	Jiménez et Asano, 2008)
31	Campo espero, grand mendoza	Argentina	Treated wastewater	Irrigation	(Jiménez et Asano, 2008)
32	Fortaleza	Brazil	Treated wastewater	Irrigation Aquaculture	(Jiménez et Asano, 2008)
33	Sao-Paulo	Brazil	Treated wastewater	Urban cleaning	(Jiménez et Asano, 2008)
34	Cochabamba	Bolivia	Treated wastewater	Irrigation	(Jiménez et Asano, 2008)
35	Antofagasta	Chile	Treated wastewater	Irrigation	(Jiménez et Asano, 2008)
36	Santiago	Chile	Treated wastewater	Irrigation	(Jiménez et Asano, 2008)
37	Ibagué	Comlombia	Treated wastewater	Irrigation	(Jiménez et Asano, 2008)
38	Porto Viejo	Equador	Treated and untreated wastewater	Irrigation	(Jiménez et Asano, 2008)
39	Solola	Guatemala	Treated wastewater	Environmental : fight against the eutrophication of the lake Atlitan	(Jiménez et Asano, 2008)
40	Luque	Paraguay	Untreated wastewater	Irrigation	(Jiménez et Asano, 2008)
41	Miraflores	Peru	Treated wastewater	Irrigation Aquaculture (Tilapia)	(Jiménez et Asano, 2008)
42	San augustin	Peru	Untreated wastewater	Irrigation	(Jiménez et Asano, 2008)
43	Taena	Peru	Untreated wastewater	Irrigation	(Jiménez et Asano, 2008)
44	La Vega	Dominican Republic	Diluted wastewater	Irrigation	(Jiménez et Asano, 2008)

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