Wastewater and Irrigated Agriculture Lessons Learned and Possible Applications in Africa

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1. Introduction

The production and discharge of domestic wastewater is rapidly increasing in developing countries due to population growth, urbanization, and economic development. There is, however, a lack of investing capacity worldwide for construction and operation of adequate treatment facilities (Van Lier and Lettinga, 1999), which threatens the quality of surface waters, soils and groundwater to which wastewater is discharged. At the same time, the water demand increases rapidly in urban and peri-urban areas, for the production of food (particularly fresh vegetables) as well as to provide income to a large group of city-dwellers and small farmers. These two trends cause an increasing use of partially treated and untreated wastewater in irrigated agriculture in and downstream of urban centres. It has been recognized that such use has additional beneficial effects, as the used water often contains important nutrients. However, unbalanced application of these nutrients as well as the presence of pollutants in wastewater has also been identified as a threat to resources (van der Zee and Shaviv, 2002; van der Zee *et al.*, 2004). The technical problem to be resolved for protecting resources is complex and broad, due to the large variety of pollutants and nutrient concentrations, of soil and geo-hydrological conditions, crops, and agricultural management (Van Asten *et al.*, 2003, 2004). Moreover, institutional problems related to risk externalities and asymmetric information among the stakeholders in the food supply chain, complicate appropriate management of wastewater irrigation and may cause failure of the wastewater for the irrigation market. The management question involves socio-economic and cultural factors which are related to e.g. policy regulations and the degree to which these are enforced, costs, benefits, and public acceptance of waste water use in irrigated agriculture, which differ between countries and often within countries. In view of the commonly regional setting of watershed hydrology, and the above mentioned complexity, the development of concepts for sustainable waste water use, and their implementation in sustainable practice are a considerable optimisation problem (Huibers *et al.*, 2002). At present, many scientific gaps on disciplinary detail issues (Kaledhonkar *et al.*, 2001), as well as the lack of a methodology for the integrated interdisciplinary problem, prevent the development of truly sustainable strategies. Hence, both scientifically and in practice (both agriculture and regulatory offices) the increasing wastewater production and growing water scarcity form an opportunity as well as an environmental conflict that has been characterized as a paralyzed situation (van Lier and Huibers, 2004).

Several initiatives have been undertaken in recent years to place the issue on the international agenda of both science and policy makers. Under the guidance of the International Water Association (IWA) a workshop was organized in Wageningen, The Netherlands, that built upon the interdisciplinary approach (Huibers and Kaspersma, 2002). An expert meeting, organised by the International Water

Management Institute (IWMI) held in Hyderabad, India, in November 2002 was concluded with The Hyderabad Declaration (http://www.iwmi.cgiar.org/home/wastewater.htm), which aimed at alerting policy makers and the research community world-wide of the importance of giving urgent attention to using wastewater for irrigation (Scott *et al.*, 2004). In many geographical regions that span major parts of the different continents international and national institutes as well as networks address problems related with irrigation, waste water treatment and its use and side effects thereof. For North Africa and adjacent Near East, researchers from Wageningen University (WU) are in dialogue with regional research institutes in several countries. In addition, discussions on an institutional level are ongoing with representatives of the World Health Organisation (WHO) in Geneva and the Food and Agriculture Organization of the United Nations (FAO) in Rome. WU researchers are also participating in networks discussing efficient water use initiative as well as various EU research projects. The objectives of this work can be summarized as follows:

1. Raise the issue of wastewater irrigation in Africa
2. Introduce basic concepts and definitions related to this issue
3. Provide a rapid overview of recent developments in the field
4. Explore the best study approach to tackle this subject. The water chain approach?
5. Seek potential African research partners for a project in preparation in The Netherlands.

This summary paper was prepared as a handout for scholars, research managers, policymakers, and water administrators from more than 20 African countries participating in the two-day Conference on Science, Technology, Water and Environmental Management held in Addis Ababa, Ethiopia, from November 29 to December 1, 2004. The conference was organized by the African Technology Policy Studies Network (ATPS).

2. Definitions

A good starting point for a successful multidisciplinary effort is to share a pool of basic concepts that are key to the subject. In this sense, some terms and items must be carefully defined in order to have a common language. In this section, a number of relevant issues regarding wastewater irrigation will be introduced.

Wastewater and sewage

Sewage is the wastewater generated by a community, namely: a) domestic wastewater, from bathrooms, toilets, kitchens, etc., b) raw or treated industrial wastewater discharged in the sewerage system, and sometimes c) rain-water and urban runoff (van Haandel and Lettinga, 1994). Domestic wastewater is the main component of sewage, and it is often taken as a synonym. Sand and coarse material (paper, bottles, etc.) are not considered part of sewage. They are transported by sewage but handled as solid waste when they arrive at a treatment facility. The sewage flow rate and composition vary considerably from place to place, depending on economic aspects, social behaviour, type and number of industries in the area, climatic conditions, water consumption, type of sewers system, etc. Besides, there are seasonal, monthly, weekly, and hourly variations in both flow rate and composition. The main pollutants in sewage are (a) suspended solids, (b) soluble organic compounds, (c) faecal pathogenic micro-organisms, and (d) nutrients, but sewage is not just made up of human excrement and water. A variety of chemicals like heavy metals, trace elements, detergents, solvents, pesticides, and other unusual compounds like pharmaceuticals, antibiotics, and hormones can also be detected in sewage. With urban runoff come potentially toxic compounds like oil from cars and pesticides that may reach the treatment plant and, eventually, a water body. Direct discharge of raw or poorly treated sewage into the environment is one of the main sources of pollution on a global scale (Gijzen, 2002). Improved sanitation would have a significant impact on people's lives in terms of safety, privacy, convenience, and dignity (United Nations, 2003). Sanitation is also a good starting point for addressing long-term poverty issues and reducing children mortality because children are more susceptible to suffer from inadequate water supply and sanitation services. The lack of water, sanitation, and hygiene for all was dubbed as "…one of the biggest scandals of the last 50 years" (WSSCC, 2003). Simple, affordable, and efficient sewage treatment systems are urgently needed, especially in developing countries, where most of the conventional technologies currently in use in industrialized nations are too expensive and complex (Grau, 1996). Sustainable sewage treatment technologies will help to preserve water ecosystems and their biodiversity, indispensable for the provision of clean water, flood control, and other vital services.

Wastewater treatment

Wastewater treatment implies the purification of a given wastewater until its characteristics achieve a certain objective, generally related to health, environmental, or economic matters. There are several technological options available for sewage treatment ranging from traditional waste stabilization ponds (WSP) to conventional aerobic systems (like trickling filters or activated sludge), from anaerobic reactors to integrated systems in which a variety of biological processes can be applied. Anaerobic processes are attracting more and more the attention of sanitary engineers and decision-makers, especially the upflow anaerobic sludge bed (or blanket) (UASB) reactor developed in the early 1970s by Lettinga and co-workers (Lettinga *et al.*, 1980). Anaerobic sewage treatment in UASB reactors is an absolute success in tropical countries like India and Brazil, but it's also finding its way in other regions, even in subtropical and more temperate countries. Recent studies showed that it can be successfully applied at temperatures as low as 15°C for a variety of different types of sewage (Mahmoud, 2002; Halalsheh, 2002; Seghezzo, 2004). Sewage treatment can be roughly classified in the following "levels":

a) Preliminary treatment. Aims at the elimination of coarse material like bottles, rugs, dead animals, stones, and so on, as well as the sand that comes with sewage. The removal is mainly due to physical actions like screening, flotation and settling. The objective of preliminary treatment is to protect pumps and pipes, protect further treatment units, and protect water bodies. The main treatment units are screens and sand traps.
b) Primary treatment. Intends to remove most of the remaining suspended solids through physical processes like flotation and settling. The objective is to protect further treatment units and protect water bodies from receiving these solids. The main units are sedimentation tanks (settlers), but also systems like septic tanks can be classified as mainly primary treatment units.
c) Secondary treatment. Aims to the elimination of organic matter through biological action (by means of bacteria, fungi, algae, protozoa, etc.). The main objective is to protect water bodies, although the production of a usable effluent is also increasingly important. Biological treatment can be accomplished either with aerobic (so as ponds) or anaerobic treatment systems (so as UASB reactors).
d) Tertiary (and even quaternary) treatment. Sometimes also called post-treatment, it intends to remove pathogens and nutrients from sewage, via chemical, photochemical, and biological action (pH, light, bacteria, algae, and fungi). The objective is to protect public health, water bodies, and to produce a usable effluent for more stringent purposes. Biological systems are mainly aerobic.

There are systems or processes that can cover two or more categories in the same treatment unit. The level of treatment to be applied depends very much on the objective set up by the administration and the use that the treated effluent will be given. However, in the vast majority of countries, tertiary treatment (or sometimes any treatment at all) is simply not affordable. Therefore, a delicate balance must be struck between the desired level of treatment, the costs of the facilities needed, and the risks related to the discharge or use of the effluent. In any case, the lack of sewage treatment is not always a technological or economic problem but a political one. In fact, governments, even from developing countries, have been spending billions of dollars on water and sanitation. However, this money is often spent on expensive, centralized, sewage treatment systems for a few privileged citizens instead of on low-cost appropriate sanitation technologies for the majority.

Wastewater irrigation

It is now acknowledged as a fact that wastewater is an important and reliable water source in many regions of the world, and that the nutrients present in wastewater may replace fertilizers saving a lot of money to farmers. In addition to that, it is also recognized that soil application can be an excellent sewage treatment system (Martijn and Huibers, 2001). Farmers not only use raw or partially treated sewage for irrigation, but also wastewater diluted with fresh water or fresh water polluted with different types of wastewater. In a sense, the use of wastewater for irrigation can be classified as direct (when it is used as such in the field) or indirect (when it was first discharged in a water body). The treatment, disposal, and use of sewage can then take different ways (**Figure 1**). Typical issues arising when a wastewater irrigation scheme is implemented are the following:

- Design choices in sanitation, collection and treatment. There are several technological alternatives for sewage collection and treatment. Traditional systems like the Waste Stabilization Ponds have to be revisited in the light of the need of avoiding evaporation that reduces the amount of water while increasing the salinity of the remaining water. The adequate degree of decentralization needs also a careful site-specific assessment.
- Mismatch between supply and demand of water. Certain storage capacity that may accommodate effluent surplus (for operational or seasonal reasons), provide water in periods of high demand and act as buffer in case of calamities may be needed. Constructed storage in an irrigation scheme might even serve as a post-treatment unit.
- Nutrient management. The amount and quality of the nutrients present in the wastewater have to be known by technicians and farmers in order to guarantee a proper application. The need of varying effluent quality during different periods of the crop period may also be an issue to discuss between farmers, irrigation experts, and treatment plant operators.
- Irrigation techniques. Techniques may vary according to the type of effluent being used and the region (watering cans, surface irrigation, drip irrigation). Special care needs to be taken to avoid contamination of the field labourers, the crops, the soil, and the surface or groundwater.
- Cropping system. Water and nutrient availability may induce significant changes in the optimal cropping system, linked to water demand, nutrient demand and seasonal aspects.
- Participatory design (farmers, engineers, policy makers). The system becomes more complex and the participation of different actors becomes indispensable to ensure a smooth process.
- Economic (costs, benefits, efficiency), social, environmental and institutional aspects that are an inextricable part of the long-term sustainability of the system.
- Risk management. Risks have to be appropriately handled at field level (proper irrigation and management techniques, contact prevention, adequate information to farmers) and at the food chain level (restricted irrigation around harvesting, washing produce with clean water, adequate information to farmers and consumers).

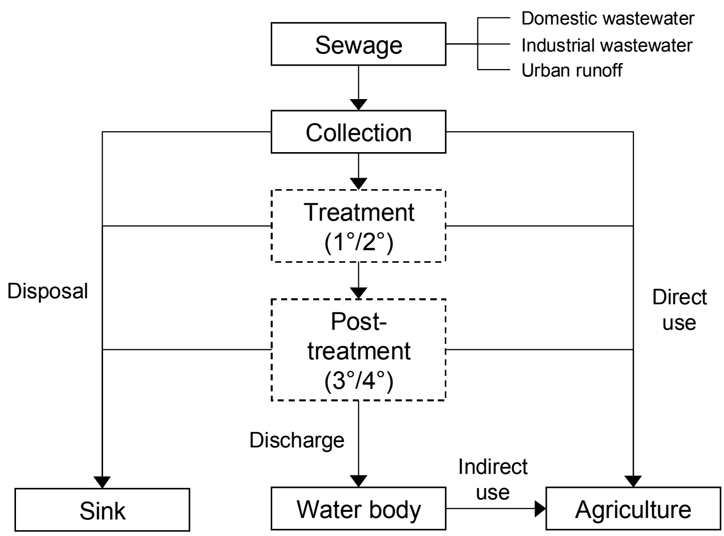

Figure 1. Basic pathways for sewage collection, treatment, disposal, and use in agriculture.

3. Lessons Learned

It is a fact that illegal, informal, unguided, or unplanned direct and indirect use of raw, partially treated, or diluted wastewater is carried out in many regions of the world. On the other hand, wastewater production from urban areas will double, if not triple, in most cities of the world in the coming 20-25 years and so will food requirements.

Typical situations

From experiences of wastewater irrigation developed in many countries of the world a number of common features has arisen, summarized in Figure 2. For example, in urban areas like Accra, Ghana (Figure 3, left), the farmer can be seen as going to the wastewater.

Farming is performed on small plots of land all year round. Mostly vegetables are grown for own consumption, while surplus is sold in the local market. It is basically a livelihood issue and the main risk is the contamination of crops with untreated wastewater. In so-called peri-urban areas like that found in Cochabamba, Bolivia (Figure 3, centre), the wastewater produced in urban areas is conveyed to the outskirts where farming actually takes place. The production is mainly seasonal; farms tend to be larger and better equipped than in the case of urban agriculture.

Less vegetables and more staple crops are grown. The main health risk found in this case is the direct contact with the wastewater, while there is a potential pollution problem downstream originated by the surpluses that are discharged untreated into surface waters. Finally, in regions like Nabeul, Tunisia (Figure 3, right), where a wastewater irrigation scheme is in place, the wastewater and the farmers move towards each other. There is a certain infrastructure, institutional arrangements and specific legislation that regulate the system.

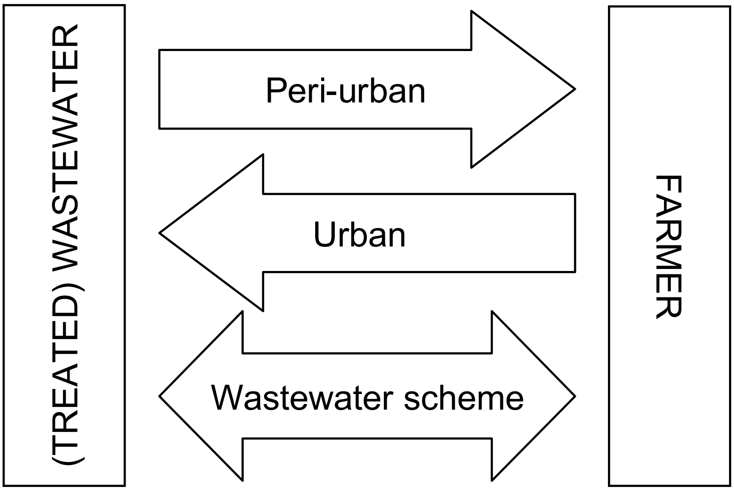

Figure 2. Typical situations encountered in wastewater irrigation around the world.

Figure 3. Wastewater irrigation in Ghana (left), Bolivia (centre), and Tunisia (right).

The water chain approach

In view of the physical and institutional complexities of wastewater irrigation systems, a so-called "water chain approach" is proposed. This approach would help to think along the line of the water flow and would be the most appropriate basis to come to an integrated design of water measures ultimately supporting environmentally safe agricultural production in urban areas and downstream. The water chain approach was discussed by Martijn and Huibers (2003), who proposed a conceptual design framework to deal with wastewater irrigation issues (**Figure 4**).

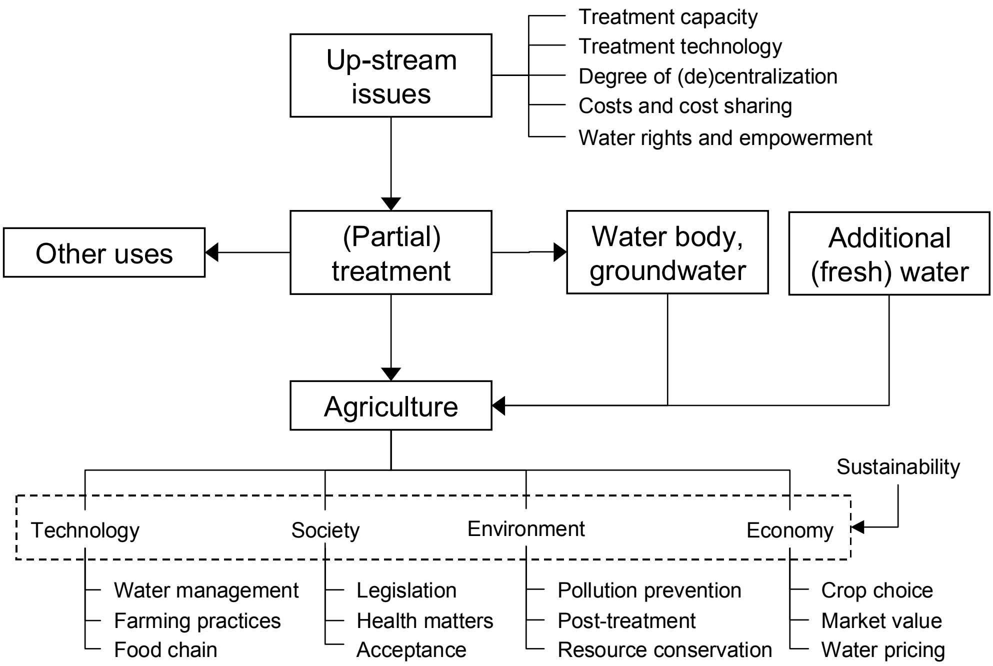

Figure 4. Conceptual design framework in wastewater irrigation.

4. Conclusions

- Wastewater irrigation has a great potential in many (developing) countries.
- It is a complex issue and should be dealt with in an integrated fashion.
- Different disciplines are required to design a wastewater irrigation system.
- Adequate water, crop, and nutrient management are required to ensure a sustainable system.
- Proper irrigation techniques need to be used according to the local situation.
- A balance between objectives, costs, and risks must be struck in each different case.
- Information must be available to all stakeholders, including the farmers.

Possible Applications in Africa

The application of wastewater irrigation systems to any situation is an open question and a challenge that needs to be solved locally. Some questions arise, like: Are the situations described above applicable to any particular situation? Who are the relevant actors in the local context? Where are the gaps in knowledge that need to be investigated and how to bridge these gaps? The relevant issues may be different depending on the type of situation, and so will be the research questions that need to be answered. For example, avoiding contamination and safeguarding health could be a hot issue in urban agriculture, while soil, surface water, and groundwater pollution may be more important in peri-urban areas. In any case, the adequate means to provide adequate information to all stakeholders seems to be particularly relevant. The Wageningen Institute for Environment and Climate Research (WIMEK/SENSE) is searching funding for a project entitled "Wastewater Treatment and Use in Irrigated Agriculture. A water chain approach". The primary aim of this Project is to identify the international institutes and networks in the subject, with which various levels of co-operation exist, which are the most appropriate groups and individual researchers for closer cooperation. Search criteria are scientific proficiency, research-funding attitude, and prominence regarding developing countries and contacts with international research funding institutions. This will enable the development in dialogue of a research program agenda addressing the scientific gaps in the water reuse approach. The outcome of this Project should be an active network, with a common agenda and a proposal to be submitted for further funding. The Project is to arrive at an agreed-upon agenda for the socio-economic and natural sciences issues that are related with the many different issues of wastewater flows, treatment and environmentally safe use in a true interdisciplinary water chain approach. This aim is essential to connect knowledge and insights of a broad range of disciplines in a context that enables to define research priorities.

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Abstract

The use of wastewater for irrigation is a fact of life in most developing countries although this practice is generally not officially recognized or even banned altogether by local governments. The use of raw or treated wastewater for irrigation allows for a more regular, year-round agriculture and can save poor people a lot of money because the nutrients present in wastewater replace most of the currently applied chemical fertilizers. Besides, soil application is an excellent and cheap sewage treatment system. In this paper, some basic concepts and definitions related to wastewater irrigation are introduced together with a brief overview of recent developments. Typical situations encountered when wastewater is used for irrigation are discussed based on practical experiences in Ghana, Tunisia, and Bolivia, and a conceptual design framework to deal with wastewater irrigation issues is proposed, based on the so-called "water chain approach". This paper was also intended to seek potential African research partners for a project in preparation in The Netherlands.

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